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Allelomimesis as escape strategy of pedestrians in two-exit confinements

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ABSTRACT

We study the efficacy of allelomimesis as an escape strategy of mobile agents (pedestrians) that aim to leave a two-exit room within the shortest possible time. Allelomimesis is the act of copying one's kindred neighbors. To escape, an agent employs one of the following strategies: (1) It chooses its own route independently (non-copying, $\alpha = 0$), (2) It imitates the actions of its neighbors at all times (blind copying, $\alpha = 1$), or (3) It either copies or acts independently according to a certain probability that is set by the copying parameter α $(0 < \alpha < 1)$. Not more than one agent could occupy a given room location. An agent's knowledge of the two exit locations is set by its information content β $(0 \leq \beta \leq 1)$. When left alone, an agent with complete knowledge of the exit whereabouts ($\beta = 1$) always takes the shortest possible path to an exit. We obtain plots of the (group) evacuation time T and exit throughput Q as functions of α and β for cases where the two exits are near (on same room side) and far (on opposite sides of room) from each other. For an isolated agent, T is inversely proportional to β. The chances of escape for an isolated agent with $\beta \leq 0.2$ are higher with adjacent exits. However, for an agent with $\beta > 0.4$ the chance is better with opposite exits. In a highly occupied room (occupancy rate $R = 80\%$) with adjacent exits, agents with $\beta > 0.8$ escape more quickly if they employ a mixed strategy of copying and non-copying $(0.4 < \alpha < 0.6)$. On the other hand, blind copying ($\alpha \approx 1$) gives agents with $\beta < 0.1$ a better chance of escaping from the same room. For the same α and R values, opposite exits allow faster evacuation for agents with $\beta < 0.1$ due to the likelihood of streaming and the lower probability of exit clogging. Streaming indicates an efficient utilization of an exit and it happens when the arcs that are formed are smaller and arch interference is less likely. Allelomimesis provides a simple yet versatile mechanism for studying the egress behavior of confined crowds in a multi-exit room.

1. Introduction

The ability of confined pedestrians to make sound decisions during (unassisted) emergency evacuations is usually hampered by an apparent narrowing of attention and a (real or perceived) reduction in the number of available escape options [1]. The situation is paralyzing and leads to a fatal slowing of the egress rate with disastrous consequences. To prevent if not minimize serious damage, strict regulations have been drawn mandating the availability of properly designed emergency escape routes in theaters, convention centers, sports stadiums and other similar infrastructures [2]. The conduct of evacuation drills could also lead to more efficient evacuation but such training exercises are generally costly and difficult to conduct in large crowds of pedestrians who are not familiar with each other.

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The number of casualties that resulted in recent emergency escape incidents has remained unacceptably high to civil society and safety engineers continue to work with architects and structural engineers to design and construct more effective escape routes that achieve an optimal balance between form and function as well as structural integrity and economic cost [2,3]. The dire consequences of emergency escapes would also be abated if we can improve our understanding of crowd dynamics — a goal that is not simple to reach since crowds are complex social systems. Crowds exhibit several forms of collective behavior that are different and not deducible from the individual performance of their constituent members [2–6].

Understanding accurately the emergence of collective behavior in crowds is difficult since even as individuals, human beings can respond differently to the same external stimuli [7,8]. The development of computationally efficient and versatile models of real world crowd systems is also essential but not easy to accomplish even for computer scientists due to the interdisciplinary nature of the crowd phenomenon [3,8,9]. In addition, the reliability of the simulation results is also difficult to test due to serious ethical and legal concerns that govern the use of innocent civilians in scientific experiments.

A number of interesting manifestations of collective behavior have been revealed by computer simulations such as clogging at exits, arch formation around an exit, disruptive interference between arcs, herding and self-organized queuing among others [9–16]. Collective behavior plays a critical role in defining the egress characteristics of confined pedestrians. Different kinds of animal systems have been utilized to test the simulation results and to probe the range of possible collective behavior of real crowds without violating ethical and legal standards [3,6,17–20].

Here, we study the efficacy of allelomimesis as an escape strategy of mobile agents (pedestrians) that aim to leave a two-exit room within the shortest possible time. Allelomimesis is the act of copying one's kindred neighbors [21]. To escape, an agent employs one of the following strategies: (1) It chooses its own route independently (non-copying, $\alpha = 0$), (2) It imitates the actions of its neighbors at all times (blind copying, $\alpha = 1$), or (3) It either copies or acts independently according to a certain probability that is set by the copying parameter (imitation tendency) α $(0 \leq \alpha \leq 1)$. Not more than one agent could occupy a given room location. An agent's knowledge of the two exit locations is set by its information content (or degree of available information) β $(0 \leq \beta \leq 1)$. When left alone, an agent with $\beta = 1$ always takes the shortest possible path to an exit. We determine the group escape time T and exit throughput Q as functions of α and β for cases where the two exits are adjacent (near) and opposite (far) each other in the room. The plots are calculated under conditions of low and high room occupancy rates.

The formation of a wide variety of real-world clusters could be explained with just one underlying clustering mechanism called allelomimesis [22,23]. Allelomimesis is considered normal behavior among social groups and surmised to be an evolutionary trait in human societies [24]. Many real-world cluster systems obey the cluster-size frequency distribution [21,22]: $D(s) \propto s^{-\tau}$, where exponent τ determines the relative abundance of the cluster sizes s. It has been previously shown that allelomimetic interactions are of three general types [22]: (1) Blind copying where agents are most likely to copy conspecifics ($\boldsymbol{\alpha} \approx 1$; e.g. tuna fish schools, buffalos, marmots), (2) Information use copying ($\boldsymbol{\alpha} \approx \tau$; e.g. urban agglomerations, firms) where agents are deliberate in the decisions whether to copy or not to copy, and (3) non-copying ($\boldsymbol{\alpha} \approx 0$; e.g. gene families, crystals, galaxies).

It is not hard to see that allelomimesis is a plausible mechanism for driving the emergence of herd behavior in crowds and animal groups. In this paper, we study how allelomimetic interactions between the mobile agents affect their ability to escape out of a two-exit room. It can be argued from experience that novice (inexperienced) agents (or those lacking in self-confidence) are likely to copy the actions of their neighbors while those with prior training are more deliberate and tend to act on their own. However, deliberate actions require longer processing times — a luxury that agents could ill-afford during emergency evacuations.

Our presentation will proceed as follows: Section 2 describes the characteristics of our agent-based model of confined mobile pedestrians in a room with exits and the simulation results are presented and analyzed in Sections 3 and 4, respectively.

2. Methodology

We implement an agent-based model to simulate the rapid exit of pedestrians out of a two-exit room. The pedestrians are viewed as discrete mobile agents in a two-dimensional lattice-like neighborhood. The agents move into adjacent lattice sites in discrete steps. The room is divided into $M \times N$ cells and each cell is either empty or occupied by not more than one agent at any given time. The total number K of agents inside the room at initial time $i = 0$, is determined by the room occupancy rate $R(\%) = 100K/MN$. The k-th agent A_k is assigned specific values for the imitation parameter α, information content β and the panic threshold ϕ where: $0 \leq \phi \leq 10$ [12,14,20]. An agent with $\phi = 0$, is calm and prefers to remain in its present position while that with a large ϕ value, has a high tendency to move to other available lattice sites. An agent with a high β value represents a pedestrian with prior knowledge of the exit locations — a condition that is realized when the exit locations are labeled with vivid exit signs or if the pedestrian has received previous training.

Agent-based modeling is an attractive tool for studying the pedestrian dynamics during emergency evacuations because of its computational simplicity and versatility [25]. It allows us to incorporate the discrete nature of pedestrians and the possible diversity of their interactions with each other [21,22]. Failure to account for discreteness in population models could lead to erroneous results [26]. Agent-based modeling produces results (at least the mean values) that are robust against