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# Animal dynamics based approach for modeling pedestrian crowd egress under panic conditions

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ABSTRACT

Collective movement is important during emergencies such as natural disasters or terrorist attacks, when rapid egress is essential for escape. The development of quantitative theories and models to explain and predict the collective dynamics of pedestrians has been hindered by the lack of complementary data under emergency conditions. Collective patterns are not restricted to humans, but have been observed in other non-human biological systems. In this study, a mathematical model for crowd panic is derived from collective animal dynamics. The development and validation of the model is supported by data from experiments with panicking Argentine ants (*Linepithema humile*). A first attempt is also made to scale the model parameters for collective pedestrian traffic from those for ant traffic, by employing a scaling concept approach commonly used in biology.



## 1. Introduction

Collective movement is important during emergencies such as natural disasters or terrorist attacks, when rapid egress is essential for escape. Collective patterns are not restricted to humans, but have been observed in other non-human biological systems. Social animals often move in groups: ant trails, wildebeest migrations, and locust swarms are some of the natural phenomena at the heart of 'movement ecology' (Holden, 2006). Although most collective movements are routine, there are rare but perilous crowd panics that may sharply affect survival and fitness, like stampedes of wildebeest under predator attack, evacuations of ant nests in the face of flooding, or flights of people from burning buildings. Not enough is known about the underlying dynamics of crowd panics, despite the obvious importance of such knowledge in the human sphere. Studies of human crowds during evacuations were carried out as early as 1930s (Kholshevnikov and Samoshin, 2008), but the problem of understanding panicking groups and enhancing safety under emergency conditions still exists (Helbing et al., 2000). The complex interactions of panicking individuals with their social and physical environments make theoretical understanding difficult. Models of pedestrian behavior in emergency situations rarely have complementary empirical data to validate the model's prediction, so we may not want to rely entirely on mathematical models before scaling up to an applied, real world situation. That lack of data is most likely a major factor explaining why very few models exist which focus on panic situations. The bulk of the literature is restricted to the study of normal (non-panic) pedestrian dynamics or normal evacuation processes (Still, 2000; Hoogendoorn and Bovy, 2002; Hoogendoorn, 2004; Daamen, 2004; Antonini et al., 2006; Kretz, 2007; Asano et al., 2009). Even the researchers who developed the few existing models of crowd panic have identified the need for more rigorous modeling frameworks and the development of approaches to assess the reliability of model predictions (Helbing et al., 2000).

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Mathematical simulation models have been used since the 1970s to study the collective movements of animals (Okubo, 1986). However, findings from such work are seldom applied to the study of collective human dynamics (Shiwakoti et al., 2009, 2010). Shiwakoti et al. (2009, 2010) highlighted the potential contribution that research with non-human organisms could make to the understanding of complex pedestrian behavior and the enhancement of pedestrian safety during emergency egress. Non-human model organisms differ in many details from humans, but they are at least living creatures and are more life-like than equations. They may be expected to behave and interact in more complex manners. In this paper, a mathematical modeling framework derived from animal dynamics is proposed for the study of crowd panic.

The paper is structured as follows. The next section details the formulation of the proposed model. The development and validation of the model is supported by data from experiments with panicking Argentine ants (*Linepithema humile*). The validation of the developed model is presented next by applying the model to simulate the collective dynamics of panicking ants. The same model is then scaled up for collective pedestrian traffic based on the scaling concept derived from biology. The final section presents the conclusions and recommendations for future research.

## 2. Model formulation

### *2.1. Background*

Like in vehicular traffic, there are microscopic, mesoscopic and macroscopic modeling approaches for pedestrian dynamics (Shiwakoti et al., 2008). This section is dedicated to the development of a microscopic model for collective pedestrian traffic under panic conditions. The microscopic approach considers the interactions between individuals and may enable better estimates of delays to pedestrians, an aspect of the dynamics that is particularly important in emergency/panic situations. The proposed model is based on observations from experiments with ants, previous studies on animal dynamics, and collective pedestrian dynamics. The model is required to simulate collective traffic across a size gap as large as ants and pedestrians. Therefore, for consistency, non-human organisms or pedestrians are referred to as ‘individuals’ throughout the model development. The pedestrian crowd is treated as an ‘emergent system’ for model formulation. Emergent systems, also referred to as self-organized systems, arise from ‘The emergence of order on a global scale through interactions on a local scale’ (Charlotte, 2005). Such order has been observed in flocks, herds, schools, etc., where entities with limited intelligence interact locally, which in turn leads to the emergence of group behavior on a global scale (Charlotte, 2005). The simplicity of such interactions in various biological entities has motivated the development of the model in this research on the assumption that pedestrian crowds act as an emergent system. Fig. 1 represents the interdependence between individual goals, interactions among individuals, and the emergent group behavior. How pedestrian crowds escape under emergency conditions is highly dependent on how the group goals and individual goals are constituted and coordinated in those situations. The basic philosophy is to address the complexity of human behavior by assigning each individual (having limited information) with simple locomotion rules as those observed from collective animal dynamics, and observing the emergent group behavior based on the local interactions of the individuals.

### *2.2. Modeling platform*

Previous studies on collective animal dynamics (Okubo, 1986) and limited studies on human panic (Helbing et al., 2000) have been based on Newton’s law of Motion. Hence it can be assumed that Newtonian mechanics can be a platform for modeling collective dynamics. Newtonian mechanics state that a temporal change of the momentum of an individual occurs in the direction of the net force which is the product of mass and acceleration as shown below

$$m_\alpha \vec{a}_\alpha = \vec{F} \tag{1}$$

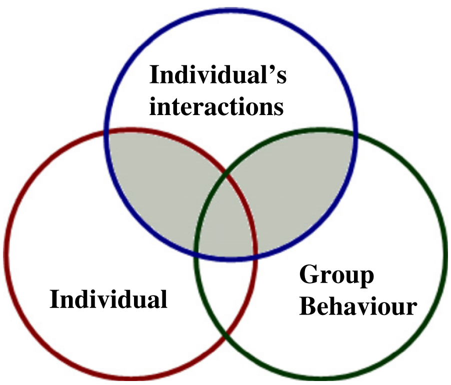


**Fig. 1.** Interdependence between the individual, interactions among individuals, and emergent group behavior.