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Behavioral Human Crowds and Society

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Abstract This chapter provides an introduction to the contents of this edited volume. In keeping with the style of the previous edited volumes, we also consider research perspectives. The first part of this chapter contributes to the selection of some key perspectives that take into account not only the technical interest of modeling and simulation, but also the impact that this research activity can have on the well-being of society. The second part provides a brief introduction to the contents of the chapters that follow this editorial introduction. The contents of the chapter refer both to the aforementioned key topics and to the contents of the preceding edited volumes [5, 8, 15].

1 Plan of the chapter

The study of human crowds has implications for a number of scientific fields that affect the well-being of citizens, such as safety problems, congestion reduction and contagion dynamics, to name but a few. Recent research suggests that an interdisciplinary approach is needed to achieve effective results for practical applications.

The previous edited volumes [5, 8, 15] have shown that a multidisciplinary approach is needed because the dynamics are behavioral, i.e. they depend heavily on human behavior at both the individual and the population level. Consequently, a wide range of skills are needed, from psychologists who can understand the cognitive and emotional factors that drive individuals, to engineers who can develop technological devices to capture the wide variety of human behavior in crowds. Cog-

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nitive and emotional factors are particularly important for modeling crowds [21], especially when it comes to capturing the behavior of pedestrians in crisis situations, such as rapid evacuation due to incidents, or when the crowd is at risk of contagion [19]. In all of these applications, social interactions strongly influence pedestrian dynamics [9, 14, 17], which in turn contribute to the spread of unusual behavior in the crowd.

This area of research has attracted considerable attention in recent years, not only for its theoretical interest, but also for its potential societal benefits. For example, computational models of crowd behavior can facilitate more effective transportation planning, which is a critical element of sustainability, reducing transportation costs and pollution while improving the overall quality of life for citizens. In addition, these models can enhance urban safety and security by using pedestrians and vehicles as sensors to detect potential threats to people and infrastructure, such as natural disasters or acts of terrorism.

This introductory chapter provides an overview of the volume, which covers various aspects of modeling, simulation, and analytic problems. Key references are the previous Volumes 1,2, and 3. Each of these volumes contains editorial chapters that carefully analyse and critique the contents [15],[8], and[5].

We begin by briefly presenting three key topics that are likely to be the focus of future research efforts by scientists. These topics are chosen according to our own bias, and although they don't encompass all current open problems, their discussion paves the way for a deeper understanding of the contents of this edited book, and it may help to foresee future directions in this challenging research area.

Key Topic 1: *Human crowds exhibit multiscale properties that cannot be reduced to a single scale of description. Specifically, the micro scale is described by individual-based models, the mesoscopic scale by kinetic models, and the macro scale by hydrodynamic models. Addressing the complexity of human crowds requires the development of a multiscale approach.*

Key Topic 2: *By leveraging artificial intelligence techniques, crowd dynamics research can benefit from improved prediction accuracy, more efficient simulations, and better decision-making in a variety of contexts, from crowd management to urban planning.*

Key Topic 3: *The modeling approach must consider multiple behavioral variables to capture the intricacies of human behavior in crowds, further emphasizing the need for a multidisciplinary approach to crowd dynamics research.*

For more information on the content of this chapter, Section 2 outlines the chapters that follow this editorial one. The reasoning presented in this section will aid in understanding the contents of the various chapters in our edited book. Section 3 proposes some perspective reasoning on the research activity that should be carried out to make seminal contributions in the challenging research fields indicated in the aforementioned key problems. As we will see, these are all interrelated

2 On the contents of the edited book

This book covers a wide range of topics related to crowd modeling, with each chapter contributing to a deeper understanding of the complex dynamics of human behavior in crowds. Chapters 2-3 deal with analytical problems related to crowd modeling which is a prerequisite for developing highly accurate models for predicting crowd dynamics Chapters 4-5 incorporate psychological features into crowd modeling. This involves taking into account the social and psychological factors that influence crowd behavior, such as emotions, communication, and decision-making processes. By incorporating these factors into models, the goal is to increase the realism of crowd simulations and improve their predictive power. Chapters 6-9 then consider more specific features of crowd behavior. These include single-file traffic, passenger movement, modeling multiple groups in crowds, and the interplay between crowd dynamics and the spread of disease.
In some more detail:

• Chapter 2 gives an overview of the analytical studies of the Hughes model for pedestrian motion. The model consists of a nonlinear conservation law coupled with an eikonal equation [2]. The authors provide a qualitative analysis based on the concept that the main difficulty in developing a mathematical theory lies in the lack of regularity of the flow in the conservation law. This peculiarity gives rise to the possibility of non-classical shocks generated non-locally by the entire distribution of pedestrians. The study also refers to [3].

• Chapter 3 outlines time-continuous pedestrian models with an emphasis on data-driven modeling [18]. The authors start with pioneering reactive force-based models and move to modern active pedestrian models with sophisticated collision avoidance and anticipation techniques. The review focuses on the mathematical aspects of the models and their various components. A study of methods for data-based calibration of model parameters through hybrid approaches using neural networks and purely data-based models adapted by deep learning, enriches the content of this chapter. This study can take advantage of empirical data on the measurement of pedestrian interaction forces [11, 12, 16].

• Chapter 4 shows that there is a need to investigate the psychological mechanisms behind observed pedestrian routing behavior as it determines the distribution of crowds over the available infrastructure [26]. The authors provide an overview of recent recent work by reviewing three experimental studies that have investigated pedestrian sensitivity to environmental information, pedestrian adherence to planned routes, and pedestrian responses to the movement of others. These studies provide evidence for some important pedestrian behaviors based on how their psychology guides their choice of specific routes.

• Chapter 5 shows how the consideration of psychological factors is essential in creating reliable models of crowd dynamics [22]. Human crowd dynamics are complex and influenced by social and psychological factors that must be taken into account in order to produce accurate models. Specifically, the authors explore the potential of using probabilistic drift-diffusion models and Bayesian inference frameworks to address human social group dynamics and support decision making. It is also highlighted that the proposed approach has significant potential for the development of artificial intelligence methods.

• Chapter 6 examines the dynamics of single-file traffic, which exhibits significant collective effects, such as stop-and-go waves, the latter being a validation benchmark for agent-based modeling approaches to traffic systems [13]. The chapter explores these models with a focus on their interrelationships, building on previous work [16]. It examines the fundamental issues associated with force-based models and classifies car-following models into two categories: stimulus-response and optimal speed models, highlighting their historical and conceptual differences.

• Chapter 7 focuses on passenger movement as a critical element of a multi-modal transportation system [25]. The chapter provides an overview of questionnaire survey-based studies aimed at understanding passenger crowd behavior in emergency situations at train stations. The study uses an approach that is believed to capture some of the likely passenger behaviors observed in documented evacuation incidents in the past. These include cooperative behaviors (e.g., helping others), reactive behaviors (e.g., waiting for instructions from the station staff), and also behaviors that could have negative consequences (e.g., pushing others).

• Chapter 8 introduces the kinetic modeling approach and shows how it can be effectively applied to model the collective behavior of human crowds [20]. The kinetic modeling of crowd dynamics with multiple groups is reviewed and some interesting features and phenomena of group dynamics in crowd motion are demonstrated through several numerical tests. The important contribution of this chapter is the study of a complex dynamics where there is an interplay between mechanical and behavioral dynamics.

• Chapter 9 focuses on modeling and simulating the spread of disease in pedestrian crowds, taking into account the impact of crowd motion in complex environments on the course of infection [24]. The authors present a redefinition of the non-local infection rate, which is crucial for linking pedestrian motion and disease spread, and model pedestrian dynamics using a kinetic equation for multi-group pedestrian flow based on a social force model, coupled with an eikonal equation. The chapter also addresses a topic that gained importance during the COVID-19 pandemic and is now one of the main motivations for studying crowd dynamics: the development of a model of interactions to account for the awareness of the risk of contagion. This model is coupled with a non-local SEIS contagion model of disease spread. In addition to modeling the effects of the number of contacts and contact duration on disease spread, the authors also consider the influence of an aerosol cloud, using a drift-diffusion model coupled to pedestrian motion.

3 Considerations for Research Prospects

This section looks ahead to research perspectives with a focus on the three key topics proposed in Section 1. Indeed, the purpose of this series of volumes on modeling and simulation of human crowds is not limited to reviewing and critically analyzing of the state of the art, but also to providing research perspectives. A common feature of all chapters is that social dynamics are a key component of the modeling approach. A broad perspective is necessary because this variable does not only refer to *stress* related to hazard perception [17, 23], but also to *awareness of contagion risk* [4], or the modeling of *antagonist groups*.

• Key Problem 1: Without claiming to be exhaustive, three important problems are brought to the attention of the interested reader: (i) the derivation of macroscopic (hydrodynamic) models from the underlying description at the microscopic scale; (ii) the derivation of models at each scale based on the same principles and using parameters with physical meaning; and (iii) the definition of a criterion for selecting the most appropriate scale for different scenarios. The first problem presents conceptual and analytical difficulties that are somehow related to the sixth Hilbert problem, see [10]. The second problem was already raised in Volume 3 [6] and then treated in [7], where models are derived that are mutually consistent at any scale. The third problem is completely open. A possible indicator might be the local density, since one can choose macroscopic models for high densities and microscopic models for low densities.

• Key Problem 2: Recent studies of crowd dynamics, see [7], have shown that pedestrian trajectories in crowds result from a decision process in which individuals first adjust their emotional state, then choose a preferred direction, and finally adapt their speed to local density conditions. In particular, the search for the preferred direction is obtained by combining the following tendencies, weighted by the local density:

1. T1: Tendency towards the exit or a preferred direction;
2. T2: Attraction by the mean stream induced by the other pedestrians;
3. T3: Search for less crowded direction with minimum density gradient.

According to [7], increasing the local density increases T2 and T3 and weakens T1, while the role of the emotional state is that increasing the stress increases T2 and weakens T1 and T3. Additional techniques can be added to model how the crowd keeps away from walls and obstacles. This approach leads to mathematical models at any scale chosen to model the dynamics, i.e., microscopic, mesoscopic and macroscopic.

This approach may seem a bit cumbersome, but it is practical because it requires only one parameter to be identified. Simulations can also take into account for the quality of the environment in which the crowds are moving, such as visibility, presence of smoke, etc. This topic is treated in [22] based on the study of individual and collective biological behavior of people in a crowd.

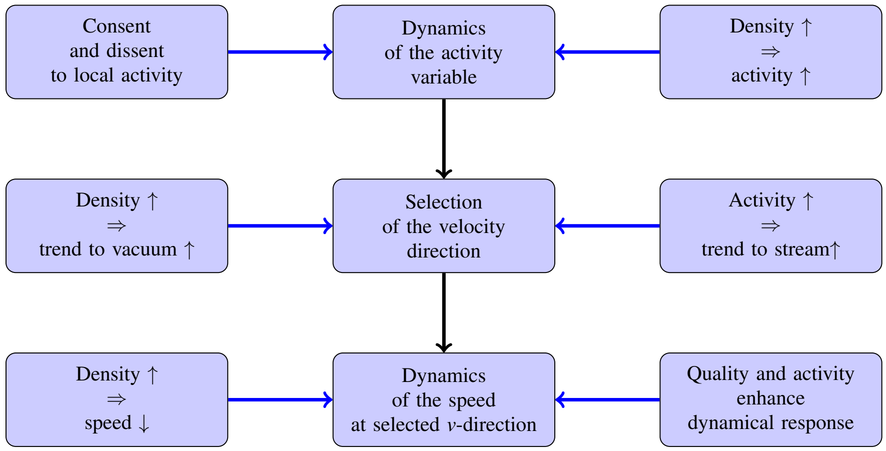

Figure 2 - From modeling interactions to derivation of crowd models.

Figure 2 shows the steps of the decision process in the central sequence of blocks, connected by dark arrows. The blocks, on the left and right sides, show how the local flow conditions and the activity variable can influence the decision process.

• Key Problem 3: To capture the intricacies of human behavior, it is necessary to use multiple behavioral variables. These can be organized into a *activity* vector. With reference to Chapters 7 and 8, the variables are stress and awareness of the risk of contagion. These variables can be assumed to be normalized over the unit interval. For stress, the limits 0 and 1 correspond to the absence of a specific walking strategy and a completely irrational walking strategy, respectively. Similarly, for contagion awareness, they correspond to no awareness and maximum awareness, respectively. See also [1, 19], where a sophisticated model is developed to describe the progression of a pathology.

In conclusion, the various chapters in this book explore these complex psychological-behavioral-mechanical dynamics, but this is only a starting point. Further theoretical and experimental studies are needed to advance our understanding of this area. It is hoped that this research will also build on the content of this book.

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