

Preface

This book presents to researchers and graduate students mathematical models and numerical simulations of crowd dynamics. The book is addressed to scholars and professionals with different backgrounds, in particular applied mathematicians, physicists, engineers, system biologists, and psychologists, who can, for various reasons, be interested in mathematical modeling of crowd behavior and, more in general, of granular flows in living and nonliving complex systems from a multiscale point of view.

In a broader sense, this book is about the *science of mathematical modeling*, seen in action under the particular perspective of pedestrian dynamics modeling. The *leading idea* is that Applied Mathematics does not just consist in the application of existing models to practical case studies but, first and foremost, in the construction of *original mathematical approaches* motivated by often nonstandard problems continuously posed by the real world. In this respect, the cultural path followed in the book encompasses rigorous procedures of mathematization of reality, analysis of the mathematical structures thereby derived, and simulation of realistic scenarios which can constitute a basis for a fruitful dialogue with non-mathematical practitioners.

Research about crowd dynamics is fostered by both theoretical and practical reasons. On the one hand, many scholars want to understand the basic principles of pedestrian motion. Their insights can often be translated into mathematical models, which can be validated through simulations. On the other hand, practitioners are interested in faithful simulations of self-organized phenomena arising in pedestrian flows, especially in complex-shaped two-dimensional built environments. Indeed, it is well known that neglecting group behaviors can lead to major safety issues. Therefore, our interest is mainly focused on models which reproduce the spontaneously emerging *self-organized collective patterns* out of an accurate and realistic design of *individual interaction rules*. Namely, without resorting to the artificial inclusion of empirical features in the mathematical equations with the primary aim of reproducing target phenomena. In this respect, we note that crowd dynamics are often nicely visualized in computer graphics animations: Our approach is rather different, since we aim at a deeper understanding, through mathematical models, of the basic dynamical principles ruling crowd behaviors. To this goal, we consider two

points of view which have been classically taken in crowd dynamics modeling: The *microscopic* one, in which pedestrians are tracked individually, and the *macroscopic* one, in which pedestrians are assimilated to a continuum and observed through their average density. We present in detail and critically analyze selected existing models. Then, as a *core topic*, we develop a *multiscale paradigm*, which allows one to bridge the various scales, taking the most from each of them in terms of capturing the relevant clues of complexity of crowds. Our background idea is indeed that most of the complex trends exhibited by crowds are due to an intrinsic interplay between *individual* and *collective behaviors*, which are capable of affecting each other. The modeling approach we promote in this book pursues actively this intuition and profits from it for designing a general multiscale mathematical method susceptible of application also in fields different from the inspiring original one.

The book is divided in two parts and eight chapters, plus two appendices. The first part, mainly introductory, is dedicated to a broad audience. It features virtual experiments pointing out, on the one hand, the phenomenology of pedestrian behaviors we are interested in and, on the other hand, the ability of our multiscale model to address such phenomena. The second part, characterized by a more technical content, presents an overview of single-scale models and the details of our multiscale approach, together with analytical and numerical results, plus its generalization to different application fields.

The hallmarks of the present work, which make it different from other books on the same topic available in the literature, can be summarized as follows:

- This book promotes a true interplay among modeling, theory, and numerics for a cutting-edge multidisciplinary research topic. One of the leading principles is that models should originate from a correct interplay between real world and mathematics.
- This book offers an accurate review of models of crowd dynamics: Both seminal and the most relevant descending works are presented with a sufficient detail to allow readers to be quickly up-to-date with the state of the art in the field.
- This book focuses on a new multiscale description of crowd dynamics, based on measure theory, which covers the full path of Applied Mathematics: Model derivation, qualitative analysis, construction and analysis of numerical schemes, and application of the algorithms to the simulation of more and less standard benchmarks in pedestrian dynamics.
- Numerical tests highlight the effects of the interplay between small and large scales on pedestrian dynamics, suggesting that crowd modeling requires definitely a multiscale approach, in which scales truly integrate and complement.
- This book provides a ready-to-implement pseudo-code version of the multiscale algorithm.

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