Preface

This book aims at integrating concepts from mathematics, physics, biology, and numerics to develop physics-based models that can be used as virtual laboratories in life science and engineering. The book title includes the word "comprehensive," which summarizes our efforts to be inclusive in terms of:

- *constitutive components* embedded within a biophysical system (e.g., fluids, solids, charged particles, mixtures);
- *biophysical laws* governing the system behavior (e.g., the Newton laws of motion, the laws of thermodynamics, and the laws of electromagnetism);
- *modeling approaches* to mathematically describe the system and its most relevant features (e.g., three-dimensional models, reduced models, lumped models);
- *methods of analysis* to theoretically investigate the system behavior (e.g., exact solutions, energy estimates, numerical approximate solutions);
- *examples in life science and bioengineering* to illustrate the impact of theoretical concepts on real-world applications (e.g., ion pumps, cell activity, blood flow).

Too many times in our careers we have experienced that these concepts, methods, and applications were to be found in different books and taught in different classes, so that it has not been always easy to connect the dots. For this reason, we felt compelled to leverage our diverse backgrounds and expertises to create an interdisciplinary comprehensive platform to approach modeling with open minds and collaborative spirits.

The workflow of this book is articulated into three main objectives. The *first objective* is to provide a systematic approach to the formulation of problems in life sciences through the adoption of mathematical models based on fundamental principles of physics, such as conservation of mass, conservation of electric charge, conservation of momentum (and angular momentum), and conservation of energy. The *second objective* is to translate the mathematical formulation into a numerical algorithm, implementable on a computer, to determine an approximation of problem solution. The *third objective* is to employ models and algorithms, the so-called computational models, as a synthesized tool for the investigation, quantification, verification, and comparison of different conjectures or scenarios regarding the behavior of a complex system. As a result of this workflow, we hope that the reader will appreciate the use of physics-based models as virtual laboratories to investigate the cause–effect relationships among mechanisms concurring to determine the functional state of a system, to test hypotheses on the system behavior, and, eventually, to formulate new hypotheses to complement experimental and clinical studies.

We truly believe that the starting point for an honest and rigorous interdisciplinary approach to scientific investigations is *communication*: if we do not understand each other, it is not possible to share our knowledge productively and build on it. For this reason, this book opens with a review of the basic concepts in mathematics, numerics, and physics (see Part 1), which provides a common language and an interpretative key for all the subsequent parts. Specifically, Part 2 and Part 3 present balance laws and constitutive relations for single and multicomponent bodies, possibly in the presence of electric charge, in the attempt to emphasize the modeling implications of the several mathematical

and physical assumptions that were necessary to derive the laws. Part 4 shows how, in some instances, the general theory can be simplified to develop effective models that retain some, if not all, of the main features of the system under investigation. Part 5 and Part 7 present a variety of applications of the general theory to problems of interest in the life sciences and bioengineering. Further topics related to computational methods that are necessary to maintain at the discrete level the mathematical and physical properties of the problems illustrated in the book are presented in Part 6.

The three of us have different backgrounds and we really strived to communicate to each other our different perspectives on each topic addressed in the book. As a matter of fact, the numerous practical examples and software codes that complement the theoretical material served, first and foremost, as a way to make things more clear to us and, in turn, hopefully, to the reader.

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