Preface

Biological systems are arguably the most complex subjects in scientific research, especially regarding the enormous range of length and time scales involved. At the molecular level, structures and dynamics involving biomolecules are highly sophisticated and stochastic. At the cellular level, numerous molecular components, many of which are unidentified, interact and organize in space and time, from which nonequilibrium physiological processes emerge at the tissue and organ levels, and beyond. While vast knowledge is accumulating for any given biological system, establishing quantitative relations between systems defined at different scales requires an integrative approach such as Multiscale Modeling (MSM).

This book is intended as a field manual for MSM methods that link at least two scales. Given the extreme diversity of the topic, the best way to learn MSM is via system-specific case studies. A quick approach toward developing a multiscale model would be to link the scales phenomenologically. Here, however, we suggest a more holistic approach, where real physical and structural information is passed across the scales. This information is becoming increasingly available via rapid advances in imaging and other measurement techniques. Furthermore, physical modeling is inevitable when considering mechanical phenomena in biology, as forces are intrinsically coupled to spatial variables in any physical process.

Among the many possible topics of MSM, our focus is on biomechanics and mechanobiology. The two terms are subtly different, yet closely correlated: Biomechanics is the study of biological systems by means of mechanical tools. It is thus often associated with the "passive" nature of a biological system including strain, stress, and stiffness. Mechanobiology is the study of the role of mechanical forces in modulating biological systems. It is associated with the "active" response of a living system including mechanoreception, signal transduction, and target activation. For a complete understanding of living systems, we have to understand both aspects equally.

The organization of this book naturally follows the biological hierarchy. At the molecular level, we focus on linking discrete and continuum descriptions of biofilaments, molecular motors, and biofilament assemblies. At the cellular level, major topics are the emergence of motile behavior, filament network-to-continuum transition, and transport phenomena. At the organ level, we review specific organ systems including tendons and ligaments, arteries, and heart valves. Through these case studies, we hope that the reader will develop “numerical instincts” to advance methods and tools and to generalize MSM to other living systems.

We would like to extend our thanks to all contributing authors whose expert contributions made this monograph possible. We would also like to thank the U.S. Interagency Modeling and Analysis Group (IMAG), in particular, Dr. Grace Peng at the National Institutes of Health, interaction with whom and the IMAG activities were one of the catalyzing factors for conceiving this edited volume. Finally, we wish to express our deepest gratitude to Ms. Gabriella Anderson and her colleagues at Springer, who provided us with the encouragement and technical assistance essential to the success of this project.

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http://www.springer.com/978-1-4471-6598-9

Multiscale Modeling in Biomechanics and
Mechanobiology
De, S.; Hwang, W.; Kuhl, E. (Eds.)
2015, VIII, 286 p. 84 illus., 63 illus. in color., Hardcover
ISBN: 978-1-4471-6598-9