

# Chapter 17

## Physiological Systems Modeling, Simulation, and Control

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### ABSTRACT

*Physiological systems modeling, simulation, and control is a research area integrating science and engineering and contributes to a continuous refinement of knowledge on how the body works. The roots of modeling a body area date back thousands of years, yet it was not until the 1950s that the tree of knowledge started to be fed with data-driven hypotheses and interventions. This chapter tries to organize disparate information of the most important modeling, simulation, and control perspectives into a coherent set of views currently applied to modern biological and medical research. It is addressed to researchers on human system physiological modeling, working both in academia and in industry to address current and future research goals.*

### 17.1. CHAPTER OBJECTIVES

It is Zeus anathema on physiological models to agonize between the Scylla of simulating a biological system and the Charybdis of controlling such systems. This chapter aims to serve as an introduction to and overview of the interdisciplinary field of modeling, simulation, and control of physiological systems. Research and applications in the area extend from cells to organs and systems, and include linear and nonlinear approaches having

time-varying or time-constant variables. Although it is not possible to cover all of the physiological modeling domains in the subsequent pages, we have made an effort to present and briefly discuss the major fields of activity in which models of biological systems are engaged. We first provide an introduction to important concepts and then we illustrate these ideas with examples acquired from physiological systems. We focus on techniques in modeling that motivate the inclusion of control mechanisms into physiological systems and

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models. In parallel, we provide methodological approaches and we discuss their advantages and limitations in order to motivate the reader to have a hands-on experience on the main modeling aspects covered.

## 17.2. INTRODUCTION

*How does an organ work? What is really happening inside a diseased organ? How can we monitor and supervise a drug molecule to help an organ work in a healthy manner? What is a healthy manner of living for a cell, organ or body anyways?* The motivation of modeling is convoluted with our distinctive characteristic of wondering. Models in physiology are mainly used for insight, description, and control. We want to know, and sometimes we need to learn, how the components of a system and their interconnections generate the overall operating characteristics of that system. We also seek to capture the characteristics of a physiological system response accurately and concisely.

In practice, the physiological modeling road does not resemble the directional straightness of a roman road. Biological signals are typically amplitude limited and distorted by colored (i.e., non-white) noise. Signal recordings have limited length and are generally nonstationary; whereas, the underlying system is either unknown or very complex to describe. But we still need models, since they can verify our designs before the prototype stage; and, even if they are not exactly accurate, they can help us gain a basic understanding of the underlying system. Models of physiological systems often aid in the specification of design criteria for the design of procedures aimed at alleviating pathological conditions. Models also summarize the physiological behavior of a system concisely, making them an appropriate testing bed for a plethora of scientific hypotheses being stated. This has also been proven useful in the design of medical devices. In a clinical setting, models

can make predictions before any intervention or after failures (lesions). Models can also be used to evaluate the functional limits of an operation, be it biological or that of an instrument interrelated with a biological system. They can also explore linear behavior at selected operating points. Lastly, physiological models provide the means (simulations) to truly explore the non-linear nature of the biological physics.

## 17.3. COMPREHENSIVE DEFINITION OF PHYSIOLOGICAL SYSTEMS MODELING, SIMULATION, AND CONTROL

In order to start thinking about modeling a system, let us begin with the parable of a Saturday theater that is crammed to suffocation by all kinds of spectators. By the end of the theatrical play, each of the spectators is asked to talk about his/her experience. One person, sitting in the last rows of the theater finds that the stage design was ingenious. Another, having the opportunity to sit in the first row of the theater is amazed by the expressiveness of the actors. A third, positioned in a corner of the theater shows a tendency to talk only for specific scenes of the play; the ones performed near his/her side. Each person, inside the theater, gives a different description of the same object; yet none keeps the ultimate truth in his/her hands.

Before projecting our parable to modeling, three aspects need to be further discussed. First, in the real world, we cannot go into the mind of the director. We do not know the script or even the number of the actors in the play; and what is more, there is no unbiased observer that holds an unconditional truth. Second, all spectators formed a personal opinion based on a hypothesis of the play that was consistent with the data they collected. This activity, which seems easy and natural to humans, is called *abduction*. Third, abduction is not an infallible way for discovering truth. This chapter describes most of the basic tools

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