Preface

The integration of data and scientific computation is driving a paradigm shift across the engineering, natural, and physical sciences. Indeed, there exists an unprecedented availability of high-fidelity measurements from time-series recordings, numerical simulations, and experimental data. When data is coupled with readily available algorithms and innovations in machine (statistical) learning, it is possible to extract meaningful spatiotemporal patterns that dominate dynamic activity. A direct implication of such data-driven modeling strategies is that we can gain traction on understanding fundamental scientific processes and also enhance our capabilities for prediction, state estimation, and control of complex systems. The ability to discover underlying principles from data has been called the *fourth paradigm of scientific discovery* [131]. Mathematical techniques geared toward characterizing patterns in data and capitalizing on the observed low-dimensional structures fall clearly within this fourth paradigm and are in ever-growing demand.

The focus of this book is on the emerging method of *dynamic mode decomposition (DMD)*. DMD is a matrix decomposition technique that is highly versatile and builds upon the power of singular value decomposition (SVD). The low-rank structures extracted from DMD, however, are associated with temporal features as well as correlated spatial activity. One only need consider the impact of principal component analysis (PCA) and Fourier transforms to understand the importance of versatile matrix decomposition methods and time-series characterizations for data analysis.

From a conceptional viewpoint, the DMD method has a rich history stemming from the seminal work of Bernard Koopman in 1931 [162] on nonlinear dynamical systems. But due to the lack of computational resources during his era, the theoretical developments were largely limited. Interest in Koopman theory was revived in 2004/05 by Mezić et al. [196, 194], with Schmid and Sesterhenn [250] and Schmid [247], in 2008 and 2010, respectively, first defining DMD as an algorithm. Rowley et al. [235] quickly realized that the DMD algorithm was directly connected to the underlying nonlinear dynamics through the Koopman operator, opening up the theoretical underpinnings for DMD theory. Thus, a great deal of credit for the success of DMD can be directly attributed to the seminal contributions of Igor Mezić (University of California, Santa Barbara), Peter Schmid (Imperial College), and Clancy Rowley (Princeton University).

This book develops the fundamental theoretical foundations of DMD and the Koopman operator. It further highlights many new innovations and algorithms that extend the range of applicability of the method. We also demonstrate how DMD can be applied in a variety of discipline-specific settings. These exemplar fields show how DMD can be used successfully for prediction, state estimation, and control of complex systems. By providing a suite of algorithms for DMD and its variants, we hope to help the practitioner quickly become fluent in this emerging method. Our aim is also to augment a traditional training in dynamical systems with a data-driven viewpoint of the field.

To aid in demonstrating the key concepts of this book, we have made extensive use of the scientific computing software MATLAB. MATLAB is one of the leading scientific computing software packages and is used across universities in the United States for teaching and learning. It is easy to use, provides high-level programming functionality, and greatly reduces the time to produce example code. The built-in algorithms developed by MATLAB allow us to easily use many of the key workhorse routines of scientific computing. Given that DMD was originally defined as an algorithm, it is fitting that the book is strongly focused on implementation and algorithm development. We are confident that the codes provided in MATLAB will not only allow for reproducible research but also enhance the learning experience for both those committed to its research implementation and those curious to dabble in a new mathematical subject. All the codes are available at www.siam.org/books/ot149.

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