Book Review
Computational topology for Biomedical Images and Data: Theory and applications

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Computational topology for Biomedical Images and Data: Theory and Applications by Rodrigo R. Moraleda, Nektarios A. Valous, Wei Xiong, and Niels Halama, CRC Press, 2019, first edition, ISBN: 9780367787875.

Big data or data analysis, of which topological data analysis is a major component, is a burgeoning field at the moment. A foray into "big data" quickly brings to front two of the central statistical challenges of our times – detection and classification of structure in extremely large, high-dimensional, data sets. Among the most intriguing new approaches to this challenge is "TDA," or "topological data analysis," the primary aim of which is providing topologically informative pre-analyses of data, which serve as input to more quantitative analyses at a later stage. It would not be a stretch to say TDA is one of the more prominent success stories in the field of applied mathematics in the recent times. The foundational pillars of TDA rest on computational topology. Modern computational topology is an amalgamation of a number of inter-related sub-areas, viz., Morse theory, homology and persistent homology. The landscape of TDA literature is vast and ever-growing, with a number of classic textbooks treating different sub-areas in great depth. Foremost amongst them, in my opinion, is the monograph *Computational Topology: An Introduction,* by Herbert Edelsbrunner and John Harer, which may rightly be regarded as the canonical textbook and reference for computational topology. Producing a monograph that stands out with a distinct personality in this landscape, and adds genuine value to it, is by no means a simple task. In writing *Computational topology for Biomedical Images and Data: Theory and Applications*, the interdisciplinary collaboration between Rodrigo R. Moraleda, Nektarios A. Valous, Wei Xiong, and Niels Halama has produced a work that will hold its own ground for a variety of reasons. The most enticing aspect of the book is the successful rendezvous between compactness and completeness. While the compactness does not allow it to cover the entire breadth of topics relevant to the field of computational topology, it is an excellent choice for the mandate that the book aspires to fulfill – introduction of computational topology as a potentially powerful tool for diagnostics associated with biomedical images and data. The completeness is reflected in a prudent selection, and rigorous treatment of the background mathematical concepts, essential towards building a functional data analysis pipeline based on tools from computational topology.

A large fraction of biomedical diagnostics is anchored on the description and analysis of images and the shapes therein. At the most basic level, topology describes shapes and connectivity. Thus analyses of biomedical images present a natural platform for the deployment of topological methods, with a potential of far reaching impact on diagnostics. As topological methods have only

recently started finding application in the analysis of biomedical data, the book makes a timely entry in the market. A data-centric approach has allowed the book to showcase the relevance and impact of esoteric theories on real-world problems. The literature on topological concepts is vast, yet the distinctive application oriented approach imparts the book a unique personality. This approach has helped the authors shape the contents that is functionally complete, and retains focus on essential topics needed to build a complete data analysis pipeline.

The first part of the book is largely devoted to laying the topological foundations. A brief discourse on group theory sets the stage for introducing topological spaces and metric spaces. A discussion on topology in metric spaces leads to the introduction of the simplicial space – the skeleton on which the computational pipeline is built in the book throughout. The remainder of the first part describes the main workhorses of the pipeline, namely, homology and persistent homology. However, the methodologies the authors adopt in describing persistent homology only allows them to talk selectively about the 0-dimensional homology group, associated with connected components. This has both advantages and disadvantages. The advantage reflects in the compactness, as well as the fact that 0-th dimensional homology group draws direct parallels with clustering analysis, and hence, is perhaps more naturally palatable to the mind of an uninitiated reader. The disadvantage clearly lies in the loss of additional, and valuable information, that the higher dimensional homology groups contain.

The rigorous yet accessible mathematical foundation built in the first part, complete with theoretical background as well as computational algorithms, is accompanied by a suite of illuminating case studies based on biomedical images and data in the second part. Readers driven by a general sense of curiosity, even if they are not directly involved in biomedical data analysis, will find the contents and presentation accessible and educational. Recognizing and characterizing noise is an essential ingredient of any robust data analysis pipeline. Commensurate with this, the first case study deals with recognizing the characteristics of noise by topological methods. The second case study demonstrates the power of persistent homology in segmentation and classification of histological images. The third and final case study concerns the analysis of point cloud data, emerging from the motivation to characterize chromatin structure during healing process caused by ionization radiation damage.

Target audience

The book is clear in its mandate of defining a target audience, namely the biomedical community. This may be a difficult task, given the vast differences in the vocabulary between the fields of computational topology and biomedical diagnostics. Readers with no prior exposure to mathematical vocabulary will find the learning curve steep and arduous. However, in my opinion, the returns will be manifold the time and effort invested, as tools from computational topology are of great use in the endeavor to classify images and data. The book targets a selected audience, but may be impactful in fields beyond its defined scope. Despite the evident focus of the book on biomedical data, the right audience includes individuals interested in data analysis across disciplines, and at all stages – from beginners to experts. Seasoned researchers in the field of applied and computational topology will find it a convenient reference manual. I would hesitate to recommend the book as a stand-alone textbook for courses on computational topology and topological data analysis, because of the lack in breadth of topics that such a course would demand. Another major impediment in its claim as a

standard text book is the lack of unsolved problem sets, as well as the unusual layout where all the figures are appended at the end of the book, which affects the flow of reading. However, I believe it has the potential to serve as a convenient, perhaps even essential, companion reference material to the classic textbooks. The numerous examples accompanying theoretical concepts throughout the book, accompanied by the rich set of case studies, leave no dearth of material and inspiration for designing potential problem sets.

Conclusion

The book successfully brings together disciplines that rarely interact, and is a glowing testimony to the impact of interdisciplinary collaborations. The symbiotic effort of a number of specialists in different areas has brought forth a creation that is complete in its demonstration of the relevance of abstract mathematical ideas in gaining deeper understanding of concrete real-life problems. The interdisciplinary expertise of the authors is evident in the deft selection and subsequent integration of cross disciplinary components in a seamless fashion. The authors have achieved a fine balance between theory and application, and the book is a pleasure to read. The book will definitely be a frequently-used and a cherished item in my personal collection. Due to the breadth in the topics covered, compactness and lucidity, it is my hope and belief that the book will quickly find itself on the shelves of students and early researchers in TDA as a must-have, yet at the same time serve as a frequent go-to reference manual for faculty and seasoned researchers.

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