Topological Data Analysis and Machine Learning Theory

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1   Persistent homology

Perhaps the most important idea in applied algebraic topology is persistence. It is a response to the first difficulty that one encounters in attempting to assign topological invariants to statistical data sets: that the topology is not robust and has a sensitive dependence on the length scale at which the data set is being considered. The solution is to calculate the topology (specifically the homology) at all scales simultaneously, and to encode the relationship between the different scales in an algebraic invariant called the persistence diagram. The effective algorithm for doing so was published in 2000 by Edelsbrunner, Letscher and Zomorodian [2]. Topological data analysis would not be possible without this tool.

Since then, persistence has been developed and understood quite extensively. Cohen-Steiner, Edelsbrunner and Harer [3] proved the important (and nontrivial) theorem that the persistence diagram is stable under perturbations of the initial data. Zomorodian and Carlson [7] studied persistence algebraically, identifying the points of the persistence diagram with indecomposable summands of a module over the polynomial ring $k[t]$, the monomial t representing a change of scale by a fixed increment. Generalising this approach using polynomial rings with two or more variables, they showed that the corresponding situation with two or more independent length scales is in some sense algebraically intractable, with no complete descriptive invariants available. Carlsson and de Silva [1] showed that persistence can be made to work over "non-monotone" parameters, in contrast to "monotone" parameters such as length scale; this is known as zigzag persistence. Bubenik and Scott [4] have described and studied persistence in terms of category theory.

Measured view.   In becoming familiar with the literature on persistence, one quickly realises that the existing mathematical foundations are dependent on certain strong finiteness assumptions. For instance, one can do persistence on the sublevelsets of a function on a compact manifold, but it is usually assumed that the function be a Morse function. This ensures that the resulting persistent data is finite: each sublevelset has finite-dimensional homology, and there are only finitely many essentially distinct levels, separated by the critical points. In computational terms, this is a perfectly natural assumption (a computer can only handle finite data), but for some of the theoretical work this assumption is

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Topology in Real-World Machine Learning and Data Analysis Kathryn Hess,Frédéric Chazal,Umberto Lupo,2022-11-07   Machine Learning In Pure Mathematics And Theoretical Physics Yang-hui He,2023-06-21 The juxtaposition of machine learning and pure mathematics and theoretical physics may first appear as contradictory in terms The rigours of proofs and derivations in the latter seem to reside in a different world from the randomness of data and statistics in the former Yet an often under appreciated component of mathematical discovery typically not presented in a final draft is experimentation both with ideas and with mathematical data Think of the teenage Gauss who conjectured the Prime Number Theorem by plotting the prime counting function many decades before complex analysis was formalized to offer a proof Can modern technology in part mimic Gauss s intuition The past five years saw an explosion of activity in using AI to assist the human mind in uncovering new mathematics finding patterns accelerating computations and raising conjectures via the machine learning of pure noiseless data The aim of this book a first of its kind is to collect research and survey articles from experts in this emerging dialogue between theoretical mathematics and machine learning It does not dwell on the well known multitude of mathematical techniques in deep learning but focuses on the reverse relationship how machine learning helps with mathematics Taking a panoramic approach the topics range from combinatorics to number theory and from geometry to quantum field theory and string theory Aimed at PhD students as well as seasoned researchers each self contained chapter offers a glimpse of an exciting future of this symbiosis   Advances in Soft Computing Lourdes Martínez-Villaseñor,Roberto A. Vázquez,Gilberto Ochoa-Ruiz,2025-10-23 The two volume set LNAI 16221 and 16222 constitutes the proceedings of the 4th Mexican International Conference on Artificial Intelligence MICAI 2025 held in Guanajuato Mexico November 3 2025 The 65 full papers presented in these proceedings were carefully reviewed and selected from 119 submissions The papers presented in these two volumes are organized in the following topical sections Part I Machine Learning Natural Language Processing and Neural Networks Part II Applications Pattern Recognition Computer Vision Image Processing and Bioinformatics Medical Applications   Artificial Neural Networks and Machine Learning – ICANN 2024 Michael Wand,Kristína Malinovská,Jürgen Schmidhuber,Igor V. Tetko,2024-09-16 The ten volume set LNCS 15016 15025 constitutes the refereed proceedings of the 33rd International Conference on Artificial Neural Networks and Machine Learning ICANN 2024 held in Lugano Switzerland during September 17 20 2024 The 294 full papers and 16 short papers included in these proceedings were carefully reviewed and selected from 764 submissions The papers cover the following topics Part I theory of neural networks and machine learning novel methods in machine learning novel neural architectures neural architecture search self organization neural processes novel architectures for computer vision and fairness in machine learning Part II computer vision classification computer vision object detection computer vision security and adversarial attacks computer vision image enhancement and computer vision 3D methods Part III computer vision

anomaly detection computer vision segmentation computer vision pose estimation and tracking computer vision video processing computer vision generative methods and topics in computer vision Part IV brain inspired computing cognitive and computational neuroscience explainable artificial intelligence robotics and reinforcement learning Part V graph neural networks and large language models Part VI multimodality federated learning and time series processing Part VII speech processing natural language processing and language modeling Part VIII biosignal processing in medicine and physiology and medical image processing Part IX human computer interfaces recommender systems environment and climate city planning machine learning in engineering and industry applications in finance artificial intelligence in education social network analysis artificial intelligence and music and software security Part X workshop AI in drug discovery workshop reservoir computing special session accuracy stability and robustness in deep neural networks special session neurorobotics and special session spiking neural networks *Foundations of Probability Theory* Himadri Deshpande,2025-02-20 Foundations of Probability Theory offers a thorough exploration of probability theory s principles methods and applications Designed for students researchers and practitioners this comprehensive guide covers both foundational concepts and advanced topics We begin with basic probability concepts including sample spaces events probability distributions and random variables progressing to advanced topics like conditional probability Bayes theorem and stochastic processes This approach lays a solid foundation for further exploration Our book balances theory and application emphasizing practical applications and real world examples We cover topics such as statistical inference estimation hypothesis testing Bayesian inference Markov chains Monte Carlo methods and more Each topic includes clear explanations illustrative examples and exercises to reinforce learning Whether you re a student building a solid understanding of probability theory a researcher exploring advanced topics or a practitioner applying probabilistic methods to solve real world problems this book is an invaluable resource We equip readers with the knowledge and tools necessary to tackle complex problems make informed decisions and explore probability theory s rich landscape with confidence **Mathematics of Intelligent Computing and Data Science** P. B. Vinod Kumar,Patrizio Frosini,P.B. Ramkumar,R. Binu,2025-03-29 This book comprises carefully selected contributions derived from plenary and invited talks delivered during the International Conference on Mathematics of Intelligent Computing and Data Science ICMICDS 22 held at the Rajagiri School of Engineering and Technology Cochin India from 15 to 17 September 2022 The volume encompasses a diverse spectrum of subjects including but not limited to artificial intelligence machine learning data analysis and optimization Acting as a valuable forum this volume offers a pivotal platform for both researchers and practitioners to showcase their scholarly endeavors It facilitates vibrant discussions on the latest advancements and serves as an avenue for the exploration of novel research trajectories within the realm of intelligent computing and data science Signal Processing and Machine Learning for Biomedical Big Data Ervin Sejdic,Tiago H. Falk,2018-07-04 Within the healthcare domain big data is defined as any high volume high diversity biological clinical

environmental and lifestyle information collected from single individuals to large cohorts in relation to their health and wellness status at one or several time points Such data is crucial because within it lies vast amounts of invaluable information that could potentially change a patient s life opening doors to alternate therapies drugs and diagnostic tools Signal Processing and Machine Learning for Biomedical Big Data thus discusses modalities the numerous ways in which this data is captured via sensors and various sample rates and dimensionalities Capturing analyzing storing and visualizing such massive data has required new shifts in signal processing paradigms and new ways of combining signal processing with machine learning tools This book covers several of these aspects in two ways firstly through theoretical signal processing chapters where tools aimed at big data be it biomedical or otherwise are described and secondly through application driven chapters focusing on existing applications of signal processing and machine learning for big biomedical data This text aimed at the curious researcher working in the field as well as undergraduate and graduate students eager to learn how signal processing can help with big data analysis It is the hope of Drs Sejdic and Falk that this book will bring together signal processing and machine learning researchers to unlock existing bottlenecks within the healthcare field thereby improving patient quality of life Provides an overview of recent state of the art signal processing and machine learning algorithms for biomedical big data including applications in the neuroimaging cardiac retinal genomic sleep patient outcome prediction critical care and rehabilitation domains Provides contributed chapters from world leaders in the fields of big data and signal processing covering topics such as data quality data compression statistical and graph signal processing techniques and deep learning and their applications within the biomedical sphere This book s material covers how expert domain knowledge can be used to advance signal processing and machine learning for biomedical big data applications **Topological Data Analysis with Applications** Gunnar Carlsson,Mikael Vejdemo-Johansson,2021-12-16 The continued and dramatic rise in the size of data sets has meant that new methods are required to model and analyze them This timely account introduces topological data analysis TDA a method for modeling data by geometric objects namely graphs and their higher dimensional versions simplicial complexes The authors outline the necessary background material on topology and data philosophy for newcomers while more complex concepts are highlighted for advanced learners The book covers all the main TDA techniques including persistent homology cohomology and Mapper The final section focuses on the diverse applications of TDA examining a number of case studies drawn from monitoring the progression of infectious diseases to the study of motion capture data Mathematicians moving into data science as well as data scientists or computer scientists seeking to understand this new area will appreciate this self contained resource which explains the underlying technology and how it can be used **Topological Data Analysis for Scientific Visualization** Julien Tierny,2018-01-16 Combining theoretical and practical aspects of topology this book provides a comprehensive and self contained introduction to topological methods for the analysis and visualization of scientific data Theoretical concepts are presented in a painstaking but intuitive manner with

numerous high quality color illustrations Key algorithms for the computation and simplification of topological data representations are described in detail and their application is carefully demonstrated in a chapter dedicated to concrete use cases With its fine balance between theory and practice Topological Data Analysis for Scientific Visualization constitutes an appealing introduction to the increasingly important topic of topological data analysis for lecturers students and researchers

Advances in data-driven approaches and modeling of complex systems Mohd Hafiz Mohd,Joel M. Addawe,Hirohide Haga,Junpyo Park,Tri Nguyen-Huu,2023-06-27 **Mathematical Principles of Topological and Geometric Data Analysis** Parvaneh Joharinad,Jürgen Jost,2023-07-29 This book explores and demonstrates how geometric tools can be used in data analysis Beginning with a systematic exposition of the mathematical prerequisites covering topics ranging from category theory to algebraic topology Riemannian geometry operator theory and network analysis it goes on to describe and analyze some of the most important machine learning techniques for dimension reduction including the different types of manifold learning and kernel methods It also develops a new notion of curvature of generalized metric spaces based on the notion of hyperconvexity which can be used for the topological representation of geometric information In recent years there has been a fascinating development concepts and methods originally created in the context of research in pure mathematics and in particular in geometry have become powerful tools in machine learning for the analysis of data The underlying reason for this is that data are typically equipped with some kind of notion of distance quantifying the differences between data points Of course to be successfully applied the geometric tools usually need to be redefined generalized or extended appropriately Primarily aimed at mathematicians seeking an overview of the geometric concepts and methods that are useful for data analysis the book will also be of interest to researchers in machine learning and data analysis who want to see a systematic mathematical foundation of the methods that they use *A Machine Learning Approach to a Problem in Exploratory Data Analysis* Jorge Muruzabal,1992 **Machine Learning and Data Mining in Pattern Recognition** ,1999

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