

Inferring Hierarchical Clustering Structures by Deterministic Annealing

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Abstract

The unsupervised detection of hierarchical structures is a major topic in unsupervised learning and one of the key questions in data analysis and representation. We propose a novel algorithm for the problem of learning decision trees for data clustering and related problems. In contrast to many other methods based on successive tree growing and pruning, we propose an objective function for tree evaluation and we derive a non-greedy technique for tree growing. Applying the principles of maximum entropy and minimum cross entropy, a deterministic annealing algorithm is derived in a meanfield approximation. This technique allows us to canonically superimpose tree structures and to fit parameters to averaged or ‘fuzzified’ trees.

Introduction

Clustering is one of the fundamental problems in exploratory data analysis. Data clustering problems occur in pattern recognition, statistics, unsupervised learning, neural networks, data mining, machine learning and many other scientific fields. The wide range of applications is explained by the fact that clustering procedures are important tools for an automated or interactive detection of structure in data sets. Especially for large data sets grouping data and extracting typical prototypes is important for a compact representation and is a precondition for further symbolic processing stages. In the context of data clustering the detection of hierarchical structures is an essential goal of data analysis. In this paper we consider binary trees with stochastic transition nodes, (Breiman *et al.* 1984) applied to vector-valued data.

We will formulate data clustering as a stochastic optimization problem to be addressed in the *maximum entropy framework*. Maximum entropy methods have been introduced as a stochastic optimization method, called *simulated annealing* in a seminal paper of Kirkpatrick *et al.* (Kirkpatrick, Gelatt, &

Vecchi 1983). To overcome the computational burden of Monte Carlo sampling, efficient *deterministic annealing* variants have been derived for a number of important optimization problems (Yuille 1990; Kosowsky & Yuille 1994; Buhmann & Hofmann 1994; Gold & Rangarajan 1996), including unconstrained clustering and vector quantization. (Rose, Gurewitz, & Fox 1990; Buhmann & Kühnel 1993). Maximum entropy methods have recently been successfully applied to the case of tree-structured vector quantization in (Miller & Rose 1994; 1996). Similar methods have also been used in the context of regression (Jordan & Jacobs 1994) and for unsupervised learning problems (Dayan, Hinton, & Zemel 1995). The key idea in simulated and deterministic annealing is to reformulate a given combinatorial optimization problem as a stochastic optimization problem. A temperature parameter T is introduced to control the amplitude of the induced noise. In the zero temperature limit, $T \rightarrow 0$, the combinatorial problem is recovered, while for high temperatures the objective function is smoothed. Tracking solutions from high temperatures thus helps us to avoid unfavorable local minima.

The major novelty of our approach is an *explicit* treatment of the topology of binary trees in the maximum entropy framework, which results in a systematic and well-founded ‘fuzzification’ of binary tree topologies. At a finite computational temperature different trees are superimposed resulting in an average tree structure. An average tree is not a single tree but a tree mixture. The proposed algorithm optimizes the tree topology jointly with all other relevant parameters, e.g. data assignments to clusters and decision node parameters.

Unconstrained Data Clustering

We restrict our attention to the case of real-valued data vectors $\mathcal{X} = \{\mathbf{x}_i \in \mathbb{R}^d : 1 \leq i \leq N\}$, and a corresponding set of prototypes $\mathcal{Y} = \{\mathbf{y}_\nu \in \mathbb{R}^d : 1 \leq \nu \leq K\}$, $K \ll N$, \mathbf{y}_ν representing a group G_ν . To describe the mapping of data vectors to prototypes we introduce an indicator function representation by Boolean assignment matrices $M \in \{0, 1\}^{N \times K}$ obeying the con-

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Data Intensive Distributed Computing: Challenges and Solutions for Large-scale Information Management Kosar, Tevfik, 2012-01-31 This book focuses on the challenges of distributed systems imposed by the data intensive applications and on the different state of the art solutions proposed to overcome these challenges Provided by publisher **Bioinformatics: Concepts, Methodologies, Tools, and Applications** Management Association, Information Resources, 2013-03-31 Bioinformatics Concepts Methodologies Tools and Applications highlights the area of bioinformatics and its impact over the medical community with its innovations that change how we recognize and care for illnesses Provided by publisher

Computational Optimization in Engineering Hossein Peyvandi, 2017-04-26 The purpose of optimization is to maximize the quality of lives productivity in time as well as interests Therefore optimization is an ongoing challenge for selecting the best possible among many other inferior designs For a hundred years in the past as optimization has been essential to human life several techniques have been developed and utilized Such a development has been one of the long lasting challenges in engineering and science and it is now clear that the optimization goals in many of real life problems are unlikely to be achieved without resource for computational techniques The history of such a development in the optimization techniques starts from the early 1950s and is still in progress Since then the efforts behind this development dedicated by many distinguished scientists mathematicians and engineers have brought us today a level of quality of lives This book concerns with the computational optimization in engineering and techniques to resolve the underlying problems in real life The current book contains studies from scientists and researchers around the world from North America to Europe and from Asia to Australia *Intelligent Information and Database Systems* Manh Thanh Le, Jerzy Swiatek, Ngoc Thanh Nguyen, 2010-03-05 The 2010 Asian Conference on Intelligent Information and Database Systems ACIIDS was the second event of the series of international scientific conferences for research and applications in the field of intelligent information and database systems The aim of ACIIDS 2010 was to provide an international forum for scientific research in the technologies and applications of intelligent information database systems and their applications ACIIDS 2010 was co organized by Hue University Vietnam and Wroclaw University of Technology Poland and took place in Hue city Vietnam during March 24 26 2010 We received almost 330 papers from 35 countries Each paper was peer reviewed by at least two members of the International Program Committee and International Reviewer Board Only 96 best papers were selected for oral presentation and publication in the two volumes of the ACIIDS 2010 proceedings The papers included in the proceedings cover the following topics artificial social systems case studies and reports on deployments collaborative learning collaborative systems and applications data warehousing and data mining database management technologies database models and query languages database security and integrity business e commerce e finance e learning systems information modeling and requirements engineering information retrieval systems intelligent agents and multi agent systems intelligent information systems intelligent internet

systems intelligent optimization techniques object relational DBMS ontologies and information sharing semi structured and XML database systems unified modeling language and unified processes Web services and Semantic Web computer networks and communication systems

Fuzzy and Neuro-Fuzzy Intelligent Systems Ernest Czogala, Jacek Leski, 2012-08-10

Intelligence systems We perform routine tasks on a daily basis as for example recognition of faces of persons also faces not seen for many years identification of dangerous situations during car driving deciding to buy or sell stock reading handwritten symbols discriminating between vines made from Sauvignon Blanc Syrah or Merlot grapes and others Human experts carry out the following diagnosing diseases localizing faults in electronic circuits optimal moves in chess games It is possible to design artificial systems to replace or duplicate the human expert There are many possible definitions of intelligence systems One of them is that an intelligence system is a system able to make decisions that would be regarded as intelligent if they were observed in humans Intelligence systems adapt themselves using some example situations inputs of a system and their correct decisions system's output The system after this learning phase can make decisions automatically for future situations This system can also perform tasks difficult or impossible to do for humans as for example compression of signals and digital channel equalization

Methods and Design Algorithms for Predictive Quantization of Signals and Images Kevin M. Holt, 2004

Intelligent Signal Processing Simon Haykin, Bart Kosko, 2001-01-15 IEEE Press is proud to present the first selected reprint volume devoted to the new field of intelligent signal processing ISP ISP differs fundamentally from the classical approach to statistical signal processing in that the input output behavior of a complex system is modeled by using intelligent or model free techniques rather than relying on the shortcomings of a mathematical model Information is extracted from incoming signal and noise data making few assumptions about the statistical structure of signals and their environment Intelligent Signal Processing explores how ISP tools address the problems of practical neural systems new signal data and blind fuzzy approximators The editors have compiled 20 articles written by prominent researchers covering 15 diverse practical applications of this nascent topic exposing the reader to the signal processing power of learning and adaptive systems This essential reference is intended for researchers professional engineers and scientists working in statistical signal processing and its applications in various fields such as humanistic intelligence stochastic resonance financial markets optimization pattern recognition signal detection speech processing and sensor fusion Intelligent Signal Processing is also invaluable for graduate students and academics with a background in computer science computer engineering or electrical engineering

About the Editors Simon Haykin is the founding director of the Communications Research Laboratory at McMaster University Hamilton Ontario Canada where he serves as university professor His research interests include nonlinear dynamics neural networks and adaptive filters and their applications in radar and communications systems Dr Haykin is the editor for a series of books on Adaptive and Learning Systems for Signal Processing Communications and Control Publisher and is both an IEEE Fellow and Fellow of the Royal Society of Canada

Bart Kosko is a past director of the University of Southern California's USC Signal and Image Processing Institute. He has authored several books including *Neural Networks and Fuzzy Systems* (Neural Networks for Signal Processing, Publisher copyright date) and *Fuzzy Thinking* (Publisher copyright date) as well as the novel *Nanotime* (Publisher copyright date). Dr. Kosko is an elected governor of the International Neural Network Society and has chaired many neural and fuzzy system conferences. Currently, he is an associate professor of electrical engineering at USC. *Applications and Science of Neural Networks, Fuzzy Systems, and Evolutionary Computation II* Bruno Bosacchi, David B. Fogel, James C. Bezdek, 1999

Applications and Science of Neural Networks, Fuzzy Systems, and Evolutionary Computation, 1999 *Journal of Machine Learning Research*, 2007 An international forum covering all areas of machine learning *Neural Networks for Signal Processing*, 1999 *Regularized Radial Basis Function Networks* Paul V. Yee, Simon Haykin, 2001-04-16 Simon Haykin is a well-known author of books on neural networks. An authoritative book dealing with cutting-edge technology. This book has no competition. ***Proceedings***, 2003 *Annual Meeting of the North American Fuzzy Information Processing Society--NAFIPS*. North American Fuzzy Information Processing Society. Annual Meeting, 2000 *Neural Networks and Learning Machines* Simon S. Haykin, 2009 For graduate-level neural network courses offered in the departments of Computer Engineering, Electrical Engineering, and Computer Science. Renowned for its thoroughness and readability, this well-organized and completely up-to-date text remains the most comprehensive treatment of neural networks from an engineering perspective. Matlab codes used for the computer experiments in the text are available for download at <http://www.pearsonhighered.com/haykin>. Refocused, revised, and renamed to reflect the duality of neural networks and learning machines, this edition recognizes that the subject matter is richer when these topics are studied together. Ideas drawn from neural networks and machine learning are hybridized to perform improved learning tasks beyond the capability of either independently. ***Medical Imaging***, 2000 ***Oceans '04 MTS/IEEE***, 2004 *Computer Vision - ACCV ...*, 1998

Materials of the Tutorial Lectures in Systems Sciences, 2001 *Recurrent Neural Networks for Prediction* Danilo P. Mandic, Jonathon A. Chambers, 2001 New technologies in engineering, physics, and biomedicine are demanding increasingly complex methods of digital signal processing. By presenting the latest research work, the authors demonstrate how real-time recurrent neural networks (RNNs) can be implemented to expand the range of traditional signal processing techniques and to help combat the problem of prediction. Within this text, neural networks are considered as massively interconnected nonlinear adaptive filters. Analyses the relationships between RNNs and various nonlinear models and filters and introduces spatio-temporal architectures together with the concepts of modularity and nesting. Examines stability and relaxation within RNNs. Presents on-line learning algorithms for nonlinear adaptive filters and introduces new paradigms which exploit the concepts of a priori and a posteriori errors, data reusing, adaptation, and normalisation. Studies convergence and stability of on-line learning algorithms based upon optimisation techniques such as contraction mapping and fixed point iteration. Describes

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