Preface to the Second Edition

Since the first edition, roughly 12 years ago, much has changed in the field of data analysis. The volume and variety of data being collected continues to increase, as has the rate (velocity) at which it is being collected and used to make decisions. Indeed, the term, Big Data, has been used to refer to the massive and diverse data sets now available. In addition, the term data science has been coined to describe an emerging area that applies tools and techniques from various fields, such as data mining, machine learning, statistics, and many others, to extract actionable insights from data, often big data.

The growth in data has created numerous opportunities for all areas of data analysis. The most dramatic developments have been in the area of predictive modeling, across a wide range of application domains. For instance, recent advances in neural networks, known as deep learning, have shown impressive results in a number of challenging areas, such as image classification, speech recognition, as well as text categorization and understanding. While not as dramatic, other areas, e.g., clustering, association analysis, and anomaly detection have also continued to advance. This new edition is in response to those advances.

Overview As with the first edition, the second edition of the book provides a comprehensive introduction to data mining and is designed to be accessible and useful to students, instructors, researchers, and professionals. Areas covered include data preprocessing, predictive modeling, association analysis, cluster analysis, anomaly detection, and avoiding false discoveries. The goal is to present fundamental concepts and algorithms for each topic, thus providing the reader with the necessary background for the application of data mining to real problems. As before, classification, association analysis and cluster analysis, are each covered in a pair of chapters. The introductory chapter covers basic concepts, representative algorithms, and evaluation techniques, while the more following chapter discusses advanced concepts and algorithms. As before, our objective is to provide the reader with a sound understanding of the foundations of data mining, while still covering many important advanced

topics. Because of this approach, the book is useful both as a learning tool and as a reference.

To help readers better understand the concepts that have been presented, we provide an extensive set of examples, figures, and exercises. The solutions to the original exercises, which are already circulating on the web, will be made public. The exercises are mostly unchanged from the last edition, with the exception of new exercises in the chapter on avoiding false discoveries. New exercises for the other chapters and their solutions will be available to instructors via the web. Bibliographic notes are included at the end of each chapter for readers who are interested in more advanced topics, historically important papers, and recent trends. These have also been significantly updated. The book also contains a comprehensive subject and author index.

What is New in the Second Edition? Some of the most significant improvements in the text have been in the two chapters on classification. The introductory chapter uses the decision tree classifier for illustration, but the discussion on many topics—those that apply across all classification approaches—has been greatly expanded and clarified, including topics such as overfitting, underfitting, the impact of training size, model complexity, model selection, and common pitfalls in model evaluation. Almost every section of the advanced classification chapter has been significantly updated. The material on Bayesian networks, support vector machines, and artificial neural networks has been significantly expanded. We have added a separate section on deep networks to address the current developments in this area. The discussion of evaluation, which occurs in the section on imbalanced classes, has also been updated and improved.

The changes in association analysis are more localized. We have completely reworked the section on the evaluation of association patterns (introductory chapter), as well as the sections on sequence and graph mining (advanced chapter). Changes to cluster analysis are also localized. The introductory chapter added the K-means initialization technique and an updated the discussion of cluster evaluation. The advanced clustering chapter adds a new section on spectral graph clustering. Anomaly detection has been greatly revised and expanded. Existing approaches—statistical, nearest neighbor/density-based, and clustering based—have been retained and updated, while new approaches have been added: reconstruction-based, one-class classification, and information-theoretic. The reconstruction-based approach is illustrated using autoencoder networks that are part of the deep learning paradigm. The data chapter has

been updated to include discussions of mutual information and kernel-based techniques.

The last chapter, which discusses how to avoid false discoveries and produce valid results, is completely new, and is novel among other contemporary textbooks on data mining. It supplements the discussions in the other chapters with a discussion of the statistical concepts (statistical significance, p-values, false discovery rate, permutation testing, etc.) relevant to avoiding spurious results, and then illustrates these concepts in the context of data mining techniques. This chapter addresses the increasing concern over the validity and reproducibility of results obtained from data analysis. The addition of this last chapter is a recognition of the importance of this topic and an acknowledgment that a deeper understanding of this area is needed for those analyzing data.

The data exploration chapter has been deleted, as have the appendices, from the print edition of the book, but will remain available on the web. A new appendix provides a brief discussion of scalability in the context of big data.

To the Instructor As a textbook, this book is suitable for a wide range of students at the advanced undergraduate or graduate level. Since students come to this subject with diverse backgrounds that may not include extensive knowledge of statistics or databases, our book requires minimal prerequisites. No database knowledge is needed, and we assume only a modest background in statistics or mathematics, although such a background will make for easier going in some sections. As before, the book, and more specifically, the chapters covering major data mining topics, are designed to be as self-contained as possible. Thus, the order in which topics can be covered is quite flexible. The core material is covered in chapters 2 (data), 3 (classification), 5 (association analysis), 7 (clustering), and 9 (anomaly detection). We recommend at least a cursory coverage of Chapter 10 (Avoiding False Discoveries) to instill in students some caution when interpreting the results of their data analysis. Although the introductory data chapter (2) should be covered first, the basic classification (3), association analysis (5), and clustering chapters (7), can be covered in any order. Because of the relationship of anomaly detection (9) to classification (3) and clustering (7), these chapters should precede Chapter 9. Various topics can be selected from the advanced classification, association analysis, and clustering chapters (4, 6, and 8, respectively) to fit the schedule and interests of the instructor and students. We also advise that the lectures be augmented by projects or practical exercises in data mining. Although they

are time consuming, such hands-on assignments greatly enhance the value of the course.

Support Materials Support materials available to all readers of this book are available at `http://www-users.cs.umn.edu/~kumar/dmbook/`.

- PowerPoint lecture slides
- Suggestions for student projects
- Data mining resources, such as algorithms and data sets
- Online tutorials that give step-by-step examples for selected data mining techniques described in the book using actual data sets and data analysis software

Additional support materials, including solutions to exercises, are available only to instructors adopting this textbook for classroom use. The book's resources will be mirrored at `www.pearsonhighered.com/cs-resources`. Comments and suggestions, as well as reports of errors, can be sent to the authors through `dmbook@cs.umn.edu`.

Acknowledgments Many people contributed to the first and second editions of the book. We begin by acknowledging our families to whom this book is dedicated. Without their patience and support, this project would have been impossible.

We would like to thank the current and former students of our data mining groups at the University of Minnesota and Michigan State for their contributions. Eui-Hong (Sam) Han and Mahesh Joshi helped with the initial data mining classes. Some of the exercises and presentation slides that they created can be found in the book and its accompanying slides. Students in our data mining groups who provided comments on drafts of the book or who contributed in other ways include Shyam Boriah, Haibin Cheng, Varun Chandola, Eric Eilertson, Levent Ertöz, Jing Gao, Rohit Gupta, Sridhar Iyer, Jung-Eun Lee, Benjamin Mayer, Aysel Ozgur, Uygar Oztekin, Gaurav Pandey, Kashif Riaz, Jerry Scripps, Gyorgy Simon, Hui Xiong, Jieping Ye, and Pusheng Zhang. We would also like to thank the students of our data mining classes at the University of Minnesota and Michigan State University who worked with early drafts of the book and provided invaluable feedback. We specifically note the helpful suggestions of Bernardo Craemer, Arifin Ruslim, Jamshid Vayghan, and Yu Wei.

Joydeep Ghosh (University of Texas) and Sanjay Ranka (University of Florida) class tested early versions of the book. We also received many useful

suggestions directly from the following UT students: Pankaj Adhikari, Rajiv Bhatia, Frederic Bosche, Arindam Chakraborty, Meghana Deodhar, Chris Everson, David Gardner, Saad Godil, Todd Hay, Clint Jones, Ajay Joshi, Joonsoo Lee, Yue Luo, Anuj Nanavati, Tyler Olsen, Sunyoung Park, Aashish Phansalkar, Geoff Prewett, Michael Ryoo, Daryl Shannon, and Mei Yang.

Ronald Kostoff (ONR) read an early version of the clustering chapter and offered numerous suggestions. George Karypis provided invaluable LaTeX assistance in creating an author index. Irene Moulitsas also provided assistance with LaTeX and reviewed some of the appendices. Musetta Steinbach was very helpful in finding errors in the figures.

We would like to acknowledge our colleagues at the University of Minnesota and Michigan State who have helped create a positive environment for data mining research. They include Arindam Banerjee, Dan Boley, Joyce Chai, Anil Jain, Ravi Janardan, Rong Jin, George Karypis, Claudia Neuhauser, Haesun Park, William F. Punch, György Simon, Shashi Shekhar, and Jaideep Srivastava. The collaborators on our many data mining projects, who also have our gratitude, include Ramesh Agrawal, Maneesh Bhargava, Steve Cannon, Alok Choudhary, Imme Ebert-Uphoff, Auroop Ganguly, Piet C. de Groen, Fran Hill, Yongdae Kim, Steve Klooster, Kerry Long, Nihar Mahapatra, Rama Nemani, Nikunj Oza, Chris Potter, Lisiane Pruinelli, Nagiza Samatova, Jonathan Shapiro, Kevin Silverstein, Brian Van Ness, Bonnie Westra, Nevin Young, and Zhi-Li Zhang.

The departments of Computer Science and Engineering at the University of Minnesota and Michigan State University provided computing resources and a supportive environment for this project. ARDA, ARL, ARO, DOE, NASA, NOAA, and NSF provided research support for Pang-Ning Tan, Michael Steinbach, Anuj Karpatne, and Vipin Kumar. In particular, Kamal Abdali, Mitra Basu, Dick Brackney, Jagdish Chandra, Joe Coughlan, Michael Coyle, Stephen Davis, Frederica Darema, Richard Hirsch, Chandrika Kamath, Tsengdar Lee, Raju Namburu, N. Radhakrishnan, James Sidoran, Sylvia Spengler, Bhavani Thuraisingham, Walt Tiernin, Maria Zemankova, Aidong Zhang, and Xiaodong Zhang have been supportive of our research in data mining and high-performance computing.

It was a pleasure working with the helpful staff at Pearson Education. In particular, we would like to thank Matt Goldstein, Kathy Smith, Carole Snyder, and Joyce Wells. We would also like to thank George Nichols, who helped with the art work and Paul Anagnostopoulos, who provided LaTeX support.

We are grateful to the following Pearson reviewers: Leman Akoglu (Carnegie Mellon University), Chien-Chung Chan (University of Akron), Zhengxin Chen

(University of Nebraska at Omaha), Chris Clifton (Purdue University), Joydeep Ghosh (University of Texas, Austin), Nazli Goharian (Illinois Institute of Technology), J. Michael Hardin (University of Alabama), Jingrui He (Arizona State University), James Hearne (Western Washington University), Hillol Kargupta (University of Maryland, Baltimore County and Agnik, LLC), Eamonn Keogh (University of California-Riverside), Bing Liu (University of Illinois at Chicago), Mariofanna Milanova (University of Arkansas at Little Rock), Srinivasan Parthasarathy (Ohio State University), Zbigniew W. Ras (University of North Carolina at Charlotte), Xintao Wu (University of North Carolina at Charlotte), and Mohammed J. Zaki (Rensselaer Polytechnic Institute).

Over the years since the first edition, we have also received numerous comments from readers and students who have pointed out typos and various other issues. We are unable to mention these individuals by name, but their input is much appreciated and has been taken into account for the second edition.