Recommender Systems: The Textbook

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Springer

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Yorktown Heights, NY, USA

ISBN 978-3-319-29657-9 ISBN 978-3-319-29659-3 (eBook)
DOI 10.1007/978-3-319-29659-3

Library of Congress Control Number: 2016931438

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

To my wife Lata, my daughter Sayani,
and my late parents Dr. Prem Sarup and Mrs. Pushplata Aggarwal.

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Preface

"*Nature shows us only the tail of the lion. But I do not doubt that the lion belongs to it even though he cannot at once reveal himself because of his enormous size.*"– Albert Einstein

The topic of recommender systems gained increasing importance in the nineties, as the Web became an important medium for business and e-commerce transactions. It was recognized early on that the Web provided unprecedented opportunities for personalization, which were not available in other channels. In particular, the Web provided ease in data collection and a user interface that could be employed to recommend items in a non-intrusive way.

Recommender systems have grown significantly in terms of public awareness since then. An evidence of this fact is that many conferences and workshops are exclusively devoted to this topic. The *ACM Conference on Recommender Systems* is particularly notable because it regularly contributes many of the cutting-edge results in this topic. The topic of recommender systems is very diverse because it enables the ability to use various types of user-preference and user-requirement data to make recommendations. The most well-known methods in recommender systems include collaborative filtering methods, content-based methods, and knowledge-based methods. These three methods form the fundamental pillars of research in recommender systems. In recent years, specialized methods have been designed for various data domains and contexts, such as time, location and social information. Numerous advancements have been proposed for specialized scenarios, and the methods have been adapted to various application domains, such as query log mining, news recommendations, and computational advertising. The organization of the book reflects these important topics. The chapters of this book can be organized into three categories:

1. *Algorithms and evaluation:* These chapters discuss the fundamental algorithms in recommender systems, including collaborative filtering methods (Chapters 2 and 4), content-based methods (Chapter 4), and knowledge-based methods (Chapter 5). Techniques for hybridizing these methods are discussed in Chapter 6. The evaluation of recommender systems is discussed in Chapter 7.

2. *Recommendations in specific domains and contexts:* The context of a recommender system plays a critical role in providing effective recommendations. For example, a

user looking for a restaurant would want to use their location as additional *context*. The context of a recommendation can be viewed as important side information that affects the recommendation goals. Different types of domains such as temporal data, spatial data, and social data, provide different types of contexts. These methods are discussed in Chapters 8, 9, 10, and 11. Chapter 11 also discusses the issue of using social information to increase the trustworthiness of the recommendation process. Recent topics such as factorization machines and trustworthy recommender systems are also covered in these chapters.

3. *Advanced topics and applications:* In Chapter 12, we discuss various robustness aspects of recommender systems, such as shilling systems, attack models, and their defenses. In addition, recent topics, such as learning to rank, multi-armed bandits, group recommender systems, multi-criteria systems, and active learning systems, are discussed in Chapter 13. An important goal of this chapter is to introduce the reader to the basic ideas and principles underlying recent developments. Although it is impossible to discuss all the recent developments in detail in a single book, it is hoped that the material in the final chapter will play the role of "breaking the ice" for the reader in terms of advanced topics. This chapter also investigates some application settings in which recommendation technology is used, such as news recommendations, query recommendations, and computational advertising. The application section provides an idea of how the methods introduced in earlier chapters apply to these different domains.

Although this book is primarily written as a textbook, it is recognized that a large portion of the audience will comprise industrial practitioners and researchers. Therefore, we have taken pains to write the book in such a way that it is also useful from an applied and reference point of view. Numerous examples and exercises have been provided to enable its use as a textbook. As most courses on recommender systems will teach only the fundamental topics, the chapters on fundamental topics and algorithms are written with a particular emphasis on classroom teaching. On the other hand, advanced industrial practitioners might find the chapters on context-sensitive recommendation useful, because many real-life applications today arise in the domains where a significant amount of contextual side-information is available. The application portion of Chapter 13 is particularly written for industrial practitioners, although instructors might find it useful towards the end of a recommender course.

We conclude with a brief introduction to the notations used in this book. This book consistently uses an $m \times n$ ratings matrix denoted by R, where m is the number of users and n is the number of items. The matrix R is typically incomplete because only a subset of entries are observed. The (i, j)th entry of R indicates the rating of user i for item j, and it is denoted by r_{ij} when it is actually observed. When the entry (i, j) is *predicted* by a recommender algorithm (rather than being specified by a user), it is denoted by $\hat{r}_{ij}$, with a "hat" symbol (i.e., a circumflex) denoting that it is a predicted value. Vectors are denoted by an "overline," as in $\overline{X}$ or $\overline{y}$.

Acknowledgments

I would like to thank my wife and daughter for their love and support during the writing of this book. I also owe my late parents a debt of gratitude for instilling in me a love of education, which has played an important inspirational role in my book-writing efforts.

This book has been written with the direct and indirect support of many individuals to whom I am grateful. During the writing of this book, I received feedback from many colleagues. In particular, I received feedback from Xavier Amatriain, Kanishka Bhaduri, Robin Burke, Martin Ester, Bart Goethals, Huan Liu, Xia Ning, Saket Sathe, Jiliang Tang, Alexander Tuzhilin, Koen Versetrepen, and Jieping Ye. I would like to thank them for their constructive feedback and suggestions. Over the years, I have benefited from the insights of numerous collaborators. These insights have influenced this book directly or indirectly. I would first like to thank my long-term collaborator Philip S. Yu for my years of collaboration with him. Other researchers with whom I have had significant collaborations include Tarek F. Abdelzaher, Jing Gao, Quanquan Gu, Manish Gupta, Jiawei Han, Alexander Hinneburg, Thomas Huang, Nan Li, Huan Liu, Ruoming Jin, Daniel Keim, Arijit Khan, Latifur Khan, Mohammad M. Masud, Jian Pei, Magda Procopiuc, Guojun Qi, Chandan Reddy, Saket Sathe, Jaideep Srivastava, Karthik Subbian, Yizhou Sun, Jiliang Tang, Min-Hsuan Tsai, Haixun Wang, Jianyong Wang, Min Wang, Joel Wolf, Xifeng Yan, Mohammed Zaki, ChengXiang Zhai, and Peixiang Zhao. I would also like to thank my advisor James B. Orlin for his guidance during my early years as a researcher.

I would also like to thank my manager Nagui Halim for providing the tremendous support necessary for the writing of this book. His professional support has been instrumental for my many book efforts in the past and present.

Finally, I would like to thank Lata Aggarwal for helping me with some of the figures drawn using Microsoft Powerpoint.

Electronic version at http://rd.springer.com/book/10.1007%2F978-3-319-29659-3

Author Biography

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He has worked extensively in the field of data mining. He has published more than 300 papers in refereed conferences and journals and authored over 80 patents. He is the author or editor of 15 books, including a textbook on data mining and a comprehensive book on outlier analysis. Because of the commercial value of his patents, he has thrice been designated a Master Inventor at IBM. He is a recipient of an IBM Corporate Award (2003) for his work on bio-terrorist threat detection in data streams, a recipient of the IBM Outstanding Innovation Award (2008) for his scientific contributions to privacy technology, a recipient of two IBM Outstanding Technical Achievement Award (2009, 2015) for his work on data streams and high-dimensional data, respectively. He received the EDBT 2014 Test of Time Award for his work on condensation-based privacy-preserving data mining. He is also a recipient of the IEEE ICDM Research Contributions Award (2015), which is one of the two highest awards for influential research contributions in the field of data mining.

He has served as the general co-chair of the IEEE Big Data Conference (2014), program co-chair of the ACM CIKM Conference (2015), IEEE ICDM Conference (2015), and the ACM KDD Conference (2016). He served as an associate editor of the IEEE Transactions on Knowledge and Data Engineering from 2004 to 2008. He is an associate editor of the ACM Transactions on Knowledge Discovery from Data, an associate editor of the IEEE Transactions on Big Data, an action editor of the Data Mining and Knowledge Discovery Journal, editor-in-chief of the ACM SIGKDD Explorations, and an associate editor of the Knowledge and Information Systems Journal. He serves on the advisory board of the Lecture Notes on Social Networks, a publication by Springer. He has served as the vice-president of the SIAM Activity Group on Data Mining. He is a fellow of the SIAM, ACM, and the IEEE, for "contributions to knowledge discovery and data mining algorithms."