

Data Mining; Concepts and Techniques

Second Edition

Jiawei Han
University of Illinois at Urbana-Champaign
Micheline Kamber

\<r-~/ *\" "

Foreword xix

Preface xxi

Chapter

I	Intro	duction I			
	1.1	What Motivated Data Mining? Why Is It Important?			
	1.2	So, What Is Data Mining? 5			
	13	Data Mining—On What Kind of Data? 9			
		1.3.1 Relational Databases 10			
		1.3.2 Data Warehouses 12			
		1.3.3 Transactional Databases 14			
		1.3.4 Advanced Data and Information Systems and Advanced Applications 15			
	1.4	Data Mining Functionalities—What Kinds of Patterns Can Be			
		Mined? 21			
		1.4,1 Concept/Class Description: Characterization and			
		Discrimination 21			
		1.4.2 Mining Frequent Patterns, Associations, and .Correlations 23			
		1.4.3 Classification and Prediction 24			
		1.4.4 Cluster Analysis 25			
		1.4.5 Outlier Analysis 26			
		1.4.6 Evolution Analysis 27			
	1.5	Are All of the Patterns Interesting? 27			
	1.6	Classification of Data Mining Systems 29			
	I 7	Data Mining Task Primitives 31			
	18	Integration of a Data Mining System with a Database or Data Warehouse System 34			
	19	Major Issues in Data Mining 36			

1.10

Summary

39

			Exercises 40 Bibliographic Notes 42
Chapter	2	Data	Preprocessing 47
		2 I	Why Preprocess the Data? 48
		2.2	Descriptive Data Summarization 51
			2.2.1 Measuring the Central Tendency 5 I
			2.2.2 Measuring the Dispersion of Data 53
			2.2.3 Graphic Displays of Basic Descriptive Data Summaries 56
		23	Data Cleaning 61
			2.3.1 Missing Values 61
			2.3.2 Noisy, Data 62
			2.3.3 Data Cleaning as a Process 65
		2.4	Data Integration and Transformation 67
			2.4.1 Data Integration 67
			2.4.2 Data Transformation 70
		2.5	Data Reduction 72
			2.5.1 Data Cube Aggregation , 73
			2.5.2 Attribute Subset Selection 752.5.3 Dimensionality Reduction 77
			2.5.3 Dimensionality Reduction 772.5.4 Numerosity Reduction 80
		2.6	Data Discretization and Concept Hierarchy Generation 86
		2.0	2.6.1 Discretization and Concept Hierarchy Generation for
			Numerical Data 88
			2.6.2 Concept Hierarchy Generation for Categorical Data 94
		2.7	Summary 97
			Exercises 97
			Bibliographic Notes 101
Chapter	3	Data	Warehouse and OLAP Technology: An Overview 105
		3 I	What Is a Data Warehouse? 105
			3.1.1 Differences between Operational Database Systems and Data Warehouses 108
			3.1.2 But, Why Have a Separate Data Warehouse? 109
		3 2	A Multidimensional Data Model 110
			3.2.1 From Tables and Spreadsheets to Data Cubes I 10
			3.2.2 Stars, Snowflakes, and Fact Constellations: Schemas for Multidimensional Databases 1 14
			3.2.3 Examples for Defining Stan Snowflake, and Fact Constellation Schemas 17

		3.2.4 Measures: Their Categorization and Computation 1 19 3.2.5 _ Concept Hierarchies 121 3.2.6 OLAP Operations in the Multidimensional Data Model 123 3.2.7 A Starnet Query Model for Querying Multidimensional Databases 126
	3.3	Data Warehouse Architecture 127
		 3.3.1 Steps for the Design and Construction of Data Warehouses 3.3.2 A Three-Tier Data Warehouse Architecture 130 3.3.3 Data Warehouse Back-End Tools and Utilities 134 3.3.4 Metadata Repository 134 3.3.5 Types of OLAP Servers: ROLAP versus MOLAP versus HOLAP 135
	3.4	Data Warehouse Implementation 137
		 3.4.1 Efficient Computation of Data Cubes 137 3.4.2 Indexing OLAP Data 141 3.4.3 Efficient Processing of OLAP Queries 144
	3.5	From Data Warehousing to Data Mining 146
		3.5.1 Data Warehouse Usage 1463.5.2 From On-Line Analytical Processing to On-Line Analytical Mining 148
	3.6	Summary 150
		Exercises 152
		Exercises 152 Bibliographic Notes I 54
Chapter 4	Data	Bibliographic Notes I 54
Chapter 4	Data	Bibliographic Notes I 54
Chapter 4		Bibliographic Notes I 54 Cube Computation and Data Generalization 157
Chapter 4		Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds
Chapter 4		Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds of Cubes 158
Chapter 4		Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds of Cubes 158 4.1.2 Multiway Array Aggregation for Full Cube Computation 164 4.1.3 BUC: Computing Iceberg Cubes from the Apex Cuboid
Chapter 4		Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds of Cubes 158 4.1.2 Multiway Array Aggregation for Full Cube Computation 164 4.1.3 BUC: Computing Iceberg Cubes from the Apex Cuboid Downward 168 4.1.4 Star-cubing: Computing Iceberg Cubes Using
Chapter 4		Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds of Cubes 158 4.1.2 Multiway Array Aggregation for Full Cube Computation 164 4.1.3 BUC: Computing Iceberg Cubes from the Apex Cuboid Downward 168 4.1.4 Star-cubing: Computing Iceberg Cubes Using a Dynamic Star-tree Structure 173 4.1.5 Precomputing Shell Fragments for Fast High-Dimensional
Chapter 4		Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds of Cubes 158 4.1.2 Multiway Array Aggregation for Full Cube Computation 164 4.1.3 BUC: Computing Iceberg Cubes from the Apex Cuboid Downward 168 4.1.4 Star-cubing: Computing Iceberg Cubes Using a Dynamic Star-tree Structure 173 4.1.5 Precomputing Shell Fragments for Fast High-Dimensional OLAP 178
Chapter 4	41	Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds of Cubes 158 4.1.2 Multiway Array Aggregation for Full Cube Computation 164 4.1.3 BUC: Computing Iceberg Cubes from the Apex Cuboid Downward 168 4.1.4 Star-cubing: Computing Iceberg Cubes Using a Dynamic Star-tree Structure 173 4.1.5 Precomputing Shell Fragments for Fast High-Dimensional OLAP 178 4.1.6 Computing Cubes with Complex Iceberg Conditions 187 Further Development of Data Cube and OLAP Technology 189 4.2.1 Discovery-Driven Exploration of Data Cubes 189
Chapter 4	41	Bibliographic Notes I 54 Cube Computation and Data Generalization 157 Efficient Methods for Data Cube Computation 157 4.1.1 A Road Map for the Materialization of Different Kinds of Cubes 158 4.1.2 Multiway Array Aggregation for Full Cube Computation 164 4.1.3 BUC: Computing Iceberg Cubes from the Apex Cuboid Downward 168 4.1.4 Star-cubing: Computing Iceberg Cubes Using a Dynamic Star-tree Structure 173 4.1.5 Precomputing Shell Fragments for Fast High-Dimensional OLAP 178 4.1.6 Computing Cubes with Complex Iceberg Conditions 187 Further Development of Data Cube and OLAP Technology 189

	4.3	Method for Data Generalization and Concept Description 198
		4.3.J Attribute-Oriented Induction for Data Characterization 199
		4.3:2 Efficient Implementation of Attribute-Oriented Induction 205
		4.3.3 Presentation of the Derived Generalization 206
		4.3.4 Mining Class Comparisons: Discriminating between
		Different Classes 210
		4.3.5 Class Description: Presentation of Both Characterization and Comparison 215
	4.4	Summary 218
		Exercises 219
		Bibliographic Notes 223
Chanter 5	Mini	ng Frequent Patterns, Associations, and Correlations 227
Onapici o	5.1	Basic Concepts and a Road Map 227
	0.1	5.1.1 Market Basket Analysis: A Motivating Example 228
		5.1.2 Frequent Itemsets, Closed Itemsets, and Association Rules 230
		5.1.3 Frequent Pattern Mining: A Road Map 232
	5.2	Efficient and Scalable Frequent Itemset Mining Methods 234
		5.2.1 The Apriori Algorithm: Finding Frequent Itemsets Using
		Candidate Generation' 234
		5.2.2 Generating Association Rules from Frequent Itemsets 239
		5.2.3 Improving the Efficiency of Apriori 240
		5.2.4 Mining Frequent Itemsets without Candidate Generation 242
		5.2.5 Mining Frequent Itemsets Using Vertical Data Format 2455.2.6 Mining Closed Frequent Itemsets 248
	5.3	·
	5.3	3
		5.3.1 Mining Multilevel Association Rules 2505.3.2 Mining Multidimensional Association Rules
		from Relational Databases and Data Warehouses 254
	5.4	From Association Mining to Correlation Analysis 259
		5.4.1 Strong Rules Are Not Necessarily Interesting: An Example 260
		5.4.2 From Association Analysis to Correlation Analysis 261
	5.5	Constraint-Based Association Mining 265
		5.5.1 Metarule-Guided Mining of Association Rules 266
		5.5.2 Constraint Pushing: Mining Guided by Rule Constraints 267
	5.6	Summary 272
		Exercises 274

Bibliographic Notes 280

Chapter	6	Class	ification and Prediction 285
		6 I	What Is Classification? What Is Prediction? 285
		6.2	Issues Regarding Classification and Prediction 289
			6.2.1 Preparing the Data for Classification and Prediction 289
			6.2.2 Comparing Classification and Prediction Methods 290
		6.3	Classification by Decision Tree Induction 291
		0.0	6.3.1 Decision Tree Induction 292
			6.3.2 Attribute Selection Measures 296
			6.3.3 Tree Pruning 304
			6.3.4 Scalability and Decision Tree Induction 306
		6.4	Bayesian Classification 310
			6.4.1 Bayes' Theorem 310
			6.4.2 Na'i've Bayesian Classification 31 I
			6.4.3 Bayesian Belief Networks 315
			6.4.4 Training Bayesian Belief Networks 317
		6.5	Rule-Based Classification 318
			6.5.1 Using IF-THEN Rules for Classification 319
			6.5.2 Rule Extraction from a Decision Tree 321
			6.5.3 Rule Induction Using a Sequential Covering Algorithm 322
		6.6	Classification by Backpropagation 327
			6.6.1 A Multilayer Feed-Forward Neural Network 328
			6.6.2 Defining a Network Topology 329
			6.6.3 Backpropagation 329
			6.6.4 Inside the Black Box: Backpropagation and Interpretability 334
		6.7	Support Vector Machines 337
			6.7.1 The Case When the Data Are Linearly Separable 337
			6.7.2 The Case When the Data Are Linearly Inseparable 342
		6.8	Associative Classification: Classification by Association
			Rule Analysis 344
		6.9	Lazy Learners (or Learning from Your Neighbors) 347
			6.9.1 /t-Nearest-Neighbor Classifiers 348
			6.9.2 Case-Based Reasoning 350
		6 10	Other Classification Methods 351
			6.10.1 Genetic Algorithms 35 I
			6.10.2 Rough Set Approach 35 I
			6.10.3 Fuzzy Set Approaches 352
		611	Prediction 354
			6.1 I.I Linear Regression 355
			6.1 12 Nonlinear Regression 357
			6.11.3 Other Regression-Based Methods 358

Chapter 7

6.12	Accuracy and Error Measures 359 6.12.1 Classifier Accuracy Measures 360 6.12.2 Predictor Error Measures 362
6.13	Evaluating the Accuracy of a Classifier or Predictor 363 6.13.1 Holdout Method and Random Subsampling 364 6.13.2 Cross-validation 364 6.13.3 Bootstrap 365
6.14	Ensemble Methods—Increasing the Accuracy 366 6.14.1 Bagging 366 '6.14.2 Boosting 367
6 15	Model Selection 370 6.15.1 Estimating Confidence Intervals 370 6.15.2 ROC Curves 372
6.16	Summary S '373
	Exercises 375
	Bibliographic Notes 378
Clus	eter Analysis 383
7.1	What Is Cluster Analysis? 383
7.2	Types of Data in Cluster Analysis 386
	7.2.1 Interval-Scaled Variables 387
	7.2.2 Binary.Vanables 389
	7.2.3 Categorical, Ordinal, and Ratio-Scaled Variables 392
	7.2.4' Variables of Mixed Types 395 7.2.5 Vector Objects 397
7.3	A Categorization of Major Clustering Methods 398
7.4	Partitioning Methods 401
	7.4.1 Classical Partitioning Methods: /c-Means and ^-Medoids 402
	7.4.2 Partitioning Methods in Large Databases: From
	fc-Medoids to CLARANS 407
75	Hierarchical Methods 408
	7.5.1 Agglomerative and Divisive Hierarchical Clustering 408
	7.5.2 BIRCH: Balanced Iterative Reducing and Clustering
	Using Hierarchies 412 7.5.3 ROCK: A Hierarchical Clustering Algorithm for Categorical Attributes 414
	7.5.4 Chameleon: A Hierarchical Clustering Algorithm
	Using Dynamic Modeling 416
7 6	Density-Based Methods 418
	7.6.1 DBSCAN: A Density-Based Clustering Method Based on Connected Regions with Sufficiently High Density 41 8

		7.6.2 OPTICS: Ordering Points to Identifythe Clustering Structure 420
		7.6.3 DENCLUE: Clustering Based on Density Distribution Functions 422
	77	Grid-Based Methods 424
		7.7.1 STING: STatistical Information Grid 425
		7.7.2 WaveCluster: Clustering Using Wavelet Transformation 427
	7 8	Model-Based Clustering Methods 429
	. 0	7.8.1 Expectation-Maximization 429
		7.8.2 Conceptual Clustering 431
		7.8.3 Neural Network Approach 433
	7.9	Clustering High-Dimensional Data 434
		7.9.1 CLIQUE: A Dimension-Growth Subspace Clustering Method 436
		7.9.2 PROCLUS: A Dimension-Reduction Subspace Clustering Method 439
		7.9.3 Frequent Pattern-Based Clustering Methods 440
	7.10	Constraint-Based Cluster Analysis 444
		7.10.1 Clustering with Obstacle Objects 446
		7.10.2 User-Constrained Cluster Analysis 448
		7.10.3 Semi-Supervised Cluster Analysis 449
	7	Outlier Analysis 451
		7.1 I.I Statistical Distribution-Based Outlier Detection 452
		7.1 12 Distance-Based Outlier Detection 454
		7.11.3 Density-Based Local Outlier Detection 455
		7.1 1.4 Deviation-Based Outlier Detection 458
	7.12	Summary 460
		Exercises 461 ''
		Bibliographic Notes 464
Chanter 8	Mini	ng Stream, Time-Series, and Sequence Data 467
Onapioi o	8.1	Mining Data Streams 468
	0.1	8.1.1 Methodologies for Stream Data Processing and
		Stream Data Systems 469
		8.1.2 Stream OLAP and Stream Data Cubes 474
		8.1.3 Frequent-Pattern Mining in Data Streams 479
		8.1.4 Classification of Dynamic Data Streams " 48 I
		8. l'.5 Clustering Evolving Data Streams 486
	8.2	Mining Time-Series Data 489
		8.2.1 Trend Analysis 490
		8.2.2 Similarity Search in Time-Series Analysis 493

Chapter 9

8.3	Mining Sequence Patterns in Transactional Databases 498						
	8.3.1	Sequential Pattern Mining: Concepts and Primitives 498					
	8.3.2	Scalable Methods for Mining Sequential Patterns 500					
	8.3.3	Constraint-Based Mining of Sequential Patterns 509					
	8.3.4	Periodicity Analysis for Time-Related Sequence Data 5 12					
8.4	Minir	ng Sequence Patterns in Biological Data 513					
	8.4.1	Alignment of Biological Sequences 514					
	8.4.2	Hidden Markov Model for Biological Sequence Analysis 5 18					
8.5	Sum	mary 527					
	Exerc	sises 528					
	Biblio	ographic Notes 531					
Grap	h Mini	ing, Social Network Analysis, and Multinational					
Data	Minin	g 535					
9 I	Grap	h Mining 535					
	9.1.1	Methods for Mining Frequent Subgraphs 536					
	9.1.2	Mining Variant and Constrained Substructure Patterns 545					
	9.1.3	Applications: Graph Indexing, Similarity Search, Classification, and Clustering 55 I					
9.2	Socia	al Network Analysis 556					
	9.2.1	What Is a Social Network? 556					
	9.2.2	Characteristics of Social Networks 557					
	9.2.3	Link Mining: Tasks and Challenges 561					
	9.2.4	Mining on Social Networks 565					
9.3	Multi	irelational Data Mining 571					
	9.3.1	What Is Multirelational Data Mining? 571					
	9.3.2	ILP Approach to Multirelational Classification 573					
	9.3.3	Tuple ID Propagation 575					
	9.3.4	Multirelational Classification Using Tuple ID Propagation 577					
	9.3.5	Multirelational Clustering with User Guidance 580					
94	Sum	mary 584					
	Exercises 586						
	Bibli	ographic Notes 587					
) Mini	na Oh	iect Snatial Multimedia Text and Web Data 591					

Chapter 10 Mining Object, Spatial, Multimedia, Text, and Web Data 591 10.1 Multidimensional Analysis and Descriptive Mining of Company of Company (1997).

10.1 Multidimensional Analysis and Descriptive Mining of Complex Data Objects 591

- 10. I.I Generalization of Structured Data 592
- 10.1.2 Aggregation and Approximation in Spatial and Multimedia Data Generalization 593

 10.1.4 Generalization of Class Composition Hierarchies 595 10.1.5 Construction and Mining of Object Cubes 596 10.1.6 Generalization-Based Mining of Plan Databases by Divide-and-Conquer 596 10.2 Spatial Data Mining 600 10.2.1 Spatial Data Cube Construction and Spatial OLAP 601 10.2.2 Mining Spatial Association and Co-location Patterns 605 10.2.3 Spatial Clustering Methods 606 10.2.4 Spatial Classification and Spatial Trend Analysis 606 10.2.5 Mining Raster Databases 607 10.3 Multimedia Data Mining 607 10.3.1 Similarity Search in Multimedia Data 608 10.3.2 Multidimensional Analysis of Multimedia Data 609 10.3.3 Classification and Prediction Analysis of Multimedia Data 61 10.3.4 Mining Associations in Multimedia Data 612 10.3.5 Audio and Video Data Mining 613 10 4 Text Mining 61 4 10.4.1 Text Data Analysis and Information Retrieval 615
10.2 Spatial Data Mining 600 10.2.1 Spatial Data Cube Construction and Spatial OLAP 601 10.2.2 Mining Spatial Association and Co-location Patterns 605 10.2.3 Spatial Clustering Methods 606 10.2.4 Spatial Classification and Spatial Trend Analysis 606 10.2.5 Mining Raster Databases 607 10.3 Multimedia Data Mining 607 10.3.1 Similarity Search in Multimedia Data 608 10.3.2 Multidimensional Analysis of Multimedia Data 609 10.3.3 Classification and Prediction Analysis of Multimedia Data 610.3.4 Mining Associations in Multimedia Data 612 10.3.5 Audio and Video Data Mining 613 10 4 Text Mining 61 4
10.2.1 Spatial Data Cube Construction and Spatial OLAP 601 10.2.2 Mining Spatial Association and Co-location Patterns 605 10.2.3 Spatial Clustering Methods 606 10.2.4 Spatial Classification and Spatial Trend Analysis 606 10.2.5 Mining Raster Databases 607 10.3 Multimedia Data Mining 607 10.3.1 Similarity Search in Multimedia Data 608 10.3.2 Multidimensional Analysis of Multimedia Data 609 10.3.3 Classification and Prediction Analysis of Multimedia Data 610 10.3.4 Mining Associations in Multimedia Data 612 10.3.5 Audio and Video Data Mining 613 10.4 Text Mining 61.4
10.3.1 Similarity Search in Multimedia Data 608 10.3.2 Multidimensional Analysis of Multimedia Data 609 10.3.3 Classification and Prediction Analysis of Multimedia Data 6 10.3.4 Mining Associations in Multimedia Data 612 10.3.5 Audio and Video Data Mining 613 10.4 Text Mining 61.4
10.3.2 Multidimensional Analysis of Multimedia Data 609 10.3.3 Classification and Prediction Analysis of Multimedia Data 6 10.3.4 Mining Associations in Multimedia Data 612 10.3.5 Audio and Video Data Mining 613 10.4 Text Mining 61.4
10 4 Text Mining 61 4
_
10.4.2 Dimensionality Reduction for Text 621 10.4.3 Text Mining Approaches 624
105 Mining the World Wide Web 628
10.5.1 Mining the Web Page Layout Structure 63010.5.2 Mining the Web's Link Structures to IdentifyAuthoritative Web Pages 631
10.5.3 Mining Multimedia Data on the Web 637
10.5.4 Automatic Classification of Web Documents 638 I 0.5.5 Web Usage Mining 640
10.6 Summary 641
Exercises 642
Bibliographic Notes 645
Applications and Trends in Data Mining 649
I I. I Data Mining Applications 649
I I.I.I Data Mining for Financial Data Analysis . 649
I 1. 12 Data Mining for the Retail Industry 651
I f. 13 Data Mining for the Telecommunication Industry 652 I 1. 1.4 Data Mining for Biological Data Analysis 654 I 1. 1.5 Data Mining in Other Scientific Applications 657

I 1. 1.6 Data Mining for Intrusion Detection 658

Chapter I

I 12	Data Mining System Products and Research Prototypes	660	
	I 121 How to Choose a Data Mining System 660		
	I 122 Examples of Commercial Data Mining Systems 663		
I 13	Additional Themes on Data Mining 665		
	I 1.3.1 Theoretical Foundations of Data Mining 665		
	I 1.3.2 Statistical Data Mining 666		
	I 1.3.3 Visual and Audio Data Mining 667		
	I 1.3.4 Data Mining and Collaborative Filtering 670		
I 1.4	Social Impacts of Data Mining 675		
	I 1.4.1 Ubiquitous and Invisible Data Mining 675		
	I 1.42 Data Mining, Privacy, and Data Security 678		
l 15	Trends in Data Mining 681		
I 1.6	Summary 684		
	Exercises ⁱ 685		
	Bibliographic Notes 687		
	Dibliographio Notes our		
Appendix	An Introduction to Microsoft's OLE DB for		
	Data Mining 691		
	A. I Model Creation 693		
	A.2 Model Training 695		
	A.3 Model Prediction and Browsing 697		
	A.5 Model Frediction and blowsing 691		
	Bibliography 703		
	Index 745		
	muex 740		