Contents

Foreword xix Preface xxi

Chapter I

Intr	oductio	n I	
1.1	Wha	t Motivated Data Mining? Why Is It Important?	I
1.2	So, V	Vhat Is Data Mining? 5	
1.3	Data	Mining—On What Kind of Data? 9	
		Relational Databases 10 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 E
	Mine	d? 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	
		Outlier Analysis 26 Evolution Analysis 27	
1.5	Are A	All of the Patterns Interesting? 27	
1.6	Class	ification of Data Mining Systems 29	
1.7	Data	Mining Task Primitives 31	
1.8		ration of a Data Mining System with tabase or Data Warehouse System 34	
1.9	Majo	r Issues in Data Mining 36	

Summary 39	3.2.4 Measures: Their Categorization and Computation 119
Exercises 40	3.2.5 Concept Hierarchies 121
Bibliographic Notes 42	3.2.6 OLAP Operations in the Multidimensional Data Model 123
Dibliographic reces 12	3.2.7 A Starnet Query Model for Querying
a Preprocessing 47	Multidimensional Databases 126
Why Preprocess the Data? 48	3.3 Data Warehouse Architecture 127
Descriptive Data Summarization 5 l	3.3.1 Steps for the Design and Construction of Data Warehouses 128
2.2.1 Measuring the Central Tendency 51	3.3.2 A Three-Tier Data Warehouse Architecture 130 3.3.3 Data Warehouse Back-End Tools and Utilities 134
2.2.2 Measuring the Dispersion of Data 53	3.3.4 Metadata Repository 134
2.2.3 Graphic Displays of Basic Descriptive Data Summaries 56	3.3.5 Types of OLAP Servers: ROLAP versus MOLAP
Data Cleaning 61	versus HOLAP 135
2.3.1 Missing Values 61	3.4 Data Warehouse Implementation 137
2.3.2 Noisy Data 62	3.4.1 Efficient Computation of Data Cubes 137
2.3.3 Data Cleaning as a Process 65	3.4.2 Indexing OLAP Data 141
Data Integration and Transformation 67	3.4.3 Efficient Processing of OLAP Queries 144
2.4.1 Data Integration 67	3.5 From Data Warehousing to Data Mining 146
2.4.2 Data Transformation 70	3.5.1 Data Warehouse Usage 146
Data Reduction 72	3.5.2 From On-Line Analytical Processing
2.5.1 Data Cube Aggregation 73	to On-Line Analytical Mining 148
2.5.2 Attribute Subset Selection 75	3.6 Summary 150
2.5.3 Dimensionality Reduction 77	Exercises 152
2.5.4 Numerosity Reduction 80	Bibliographic Notes 154
Data Discretization and Concept Hierarchy Generation 86	
2.6.1 Discretization and Concept Hierarchy Generation for	Chapter 4 Data Cube Computation and Data Generalization 157
Numerical Data 88 2.6.2 Concept Hierarchy Generation for Categorical Data 94	4. Efficient Methods for Data Cube Computation 157
	4.1.1 A Road Map for the Materialization of Different Kinds
Summary 97	of Cubes 158
Exercises 97	4.1.2 Multiway Array Aggregation for Full Cube Computation 164
Bibliographic Notes 101	4.1.3 BUC: Computing Iceberg Cubes from the Apex Cuboid
a Warehouse and OLAP Technology: An Overview 105	Downward 168
What Is a Data Warehouse? 105	4.1.4 Star-cubing: Computing Iceberg Cubes Using
3.1.1 Differences between Operational Database Systems	a Dynamic Star-tree Structure 173
and Data Warehouses 108	4.1.5 Precomputing Shell Fragments for Fast High-Dimensional OLAP 178
3.1.2 But, Why Have a Separate Data Warehouse? 109	4.1.6 Computing Cubes with Complex Iceberg Conditions 187
A Multidimensional Data Model 110	4.2 Further Development of Data Cube and OLAP
3.2.1 From Tables and Spreadsheets to Data Cubes 110	Technology 189
3.2.2 Stars, Snowflakes, and Fact Constellations:	4.2.1 Discovery-Driven Exploration of Data Cubes 189
Schemas for Multidimensional Databases 114	4.2.2 Complex Aggregation at Multiple Granularity:
3.2.3 Examples for Defining Star, Snowflake,	Multifeature Cubes 192
and Fact Constellation Schemas 117	4.2.3 Constrained Gradient Analysis in Data Cubes 195

334

4.3 Attribute-Oriented Induction—An A			
Method for Data Generalization and		Chapter 6 Class	sification and Prediction 285
4.3.1 Attribute-Oriented Induction for Da	ata Characterization 199	Chapter o Class	What Is Classification? What Is Prediction? 285
4.3.2 Efficient Implementation of Attribute	e-Oriented Induction 205	6.2	Issues Regarding Classification and Prediction 289
4.3.3 Presentation of the Derived Genera		0.2	6.2.1 Preparing the Data for Classification and Prediction 289
4.3.4 Mining Class Comparisons: Discrimin	nating between		6.2.2 Comparing Classification and Prediction Methods 290
Different Classes 210 4.3.5 Class Description: Presentation of B	20th Characterization		Classification by Decision Tree Induction 291
and Comparison 215	our Characterization .		6.3.1 Decision Tree Induction 292
4.4 Summary 218			6.3.2 Attribute Selection Measures 296
Exercises 219			6.3.3 Tree Pruning 304
Bibliographic Notes 223			6.3.4 Scalability and Decision Tree Induction 306
Dibliographic ractes 223		6.4	Bayesian Classification 310
			6.4.1 Bayes' Theorem 310
			6.4.2 Naïve Bayesian Classification 311 6.4.3 Bayesian Belief Networks 315
Mining Frequent Patterns, Associations, an	nd Correlations 227		6.4.4 Training Bayesian Belief Networks 317
Basic Concepts and a Road Map 22	.7	65	Rule-Based Classification 318
5.1.1 Market Basket Analysis: A Motivating	g Example 228	0.0	6.5.1 Using IF-THEN Rules for Classification 319
5.1.2 Frequent Itemsets, Closed Itemsets,			6.5.2 Rule Extraction from a Decision Tree 321
5.1.3 Frequent Pattern Mining: A Road Ma			6.5.3 Rule Induction Using a Sequential Covering Algorithm 32
Efficient and Scalable Frequent Item		6.6	Classification by Backpropagation 327
5.2.1 The Apriori Algorithm: Finding Frequency	uent Itemsets Using		6.6.1 A Multilayer Feed-Forward Neural Network 328
Candidate Generation 234 5.2.2 Generating Association Rules from F	Frequent Itemsets 239		6.6.2 Defining a Network Topology 329
5.2.3 Improving the Efficiency of Apriori			6.6.3 Backpropagation 329
5.2.4 Mining Frequent Itemsets without C			6.6.4 Inside the Black Box: Backpropagation and Interpretability
5.2.5 Mining Frequent Itemsets Using Vert		6.7	Support Vector Machines 337 6.7.1 The Case When the Data Are Linearly Separable 337
5.2.6 Mining Closed Frequent Itemsets 2			6.7.1 The Case When the Data Are Linearly Inseparable 342
Mining Various Kinds of Association		6.8	Associative Classification: Classification by Association
5.3.1 Mining Multilevel Association Rules		0.0	Rule Analysis 344
5.3.2 Mining Multidimensional Association from Relational Databases and Data		6.9	Lazy Learners (or Learning from Your Neighbors) 34
From Association Mining to Correlate			6.9.1 k -Nearest-Neighbor Classifiers 348
5.4.1 Strong Rules Are Not Necessarily In			6.9.2 Case-Based Reasoning 350
5.4.2 From Association Analysis to Correla	ation Analysis 261	6.10	Other Classification Methods 351
5.5 Constraint-Based Association Mining			6.10.1 Genetic Algorithms 351
5.5.1 Metarule-Guided Mining of Associati			6.10.2 Rough Set Approach 351
5.5.2 Constraint Pushing: Mining Guided b			6.10.3 Fuzzy Set Approaches 352
5.6 Summary 272		6.11	Prediction 354
Exercises 274			6.11.1 Linear Regression 355 6.11.2 Nonlinear Regression 357
Bibliographic Notes 280			6.11.2 Other Regression-Based Methods 358

6.12	Accuracy and Error Measures 359
0.12	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 373
	Exercises 375
	Bibliographic Notes 378
Clus	ter 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 Variables 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
	7/1 Classical David' ' N/11 1 7 N/
	7.4.1 Classical Partitioning Methods: <i>k</i> -Means and <i>k</i> -Medoids 402 7.4.2 Partitioning Methods in Large Databases: From <i>k</i> -Medoids to CLARANS 407
7.5	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 418

	7.6.2	OPTICS: Ordering Points to Identify the Clustering
	7.6.3	Structure 420 DENCLUE: Clustering Based on Density Distribution Functions 422
7	Grid-	Based Methods 424
		STING: STatistical INformation Grid 425
•		WaveCluster: Clustering Using Wavelet Transformation 427
3	to a series	el-Based Clustering Methods 429
	7.8.1	
		Conceptual Clustering 431
2		Neural Network Approach 433
7		ering High-Dimensional Data 434
		CLIQUE: A Dimension-Growth Subspace Clustering Method 4 PROCLUS: A Dimension-Reduction Subspace Clustering Method 439
	7.9.3	Frequent Pattern-Based Clustering Methods 440
10	Cons	traint-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
	Outli	er Analysis 45 l
	7.11.2 7.11.3	Statistical Distribution-Based Outlier Detection 452 Distance-Based Outlier Detection 454 Density-Based Local Outlier Detection 455 Deviation-Based Outlier Detection 458
12	Sumn	nary 460
	Exerc	ises 461
	Biblio	graphic Notes 464

Chapter 8 Mining Stream, Time-Series, and Sequence Data 467

8.1. Methodologies for Stream D

- 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 481
 - 8.1.5 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

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 512
0.4	
8.4	Filling Sequence Factorins in District Fild
	8.4.1 Alignment of Biological Sequences 514 8.4.2 Hidden Markov Model for Biological Sequence Analysis 518
8.5	Summary 527
0.5	Exercises 528
	Bibliographic Notes 531
	h Mining, Social Network Analysis, and Multirelational
Data	Mining 535
9.1	Graph 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	Social Network Analysis 556
7.2	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	Multirelational 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
9.4	Summary 584
	Exercises 586
	Bibliographic Notes 587
) Mini	ng Object, Spatial, Multimedia, Text, and Web Data 591
10.1	Multidimensional Analysis and Descriptive Mining of Complex

Data Objects 591

10.1.1 Generalization of Structured Data 592

Generalization 593

10.1.2 Aggregation and Approximation in Spatial and Multimedia Data

		10.1.3 Generalization of Object Identifiers and Class/Subclass Hierarchies 594
		 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 614
		10.4.1 Text Data Analysis and Information Retrieval 61510.4.2 Dimensionality Reduction for Text 62110.4.3 Text Mining Approaches 624
	10.5	Mining the World Wide Web 628
		 10.5.1 Mining the Web Page Layout Structure 630 10.5.2 Mining the Web's Link Structures to Identify Authoritative Web Pages 631 10.5.3 Mining Multimedia Data on the Web 637
		10.5.4 Automatic Classification of Web Documents 638 10.5.5 Web Usage Mining 640
	10.6	Summary 641
		Exercises 642
		Bibliographic Notes 645
Chapter	Appl	ications and Trends in Data Mining 649
	11.1	Data Mining Applications 649
		11.1.1 Data Mining for Financial Data Analysis 649

11.1.2 Data Mining for the Retail Industry 651

11.1.4 Data Mining for Biological Data Analysis 654

11.1.6 Data Mining for Intrusion Detection 658

11.1.5 Data Mining in Other Scientific Applications 657

11.1.3 Data Mining for the Telecommunication Industry 652

11.2	Data Mining System Products and Research Prototypes	660
	11.2.1 How to Choose a Data Mining System 660	
	11.2.2 Examples of Commercial Data Mining Systems 663	
11.3	Additional Themes on Data Mining 665	
	11.3.1 Theoretical Foundations of Data Mining 665	
	11.3.2 Statistical Data Mining 666	
	11.3.3 Visual and Audio Data Mining 667	
	11.3.4 Data Mining and Collaborative Filtering 670	
11.4		
	11.4.1 Ubiquitous and Invisible Data Mining 675	
	11.4.2 Data Mining, Privacy, and Data Security 678	
11.5	Trends in Data Mining 681	
11.6	Summary 684	
	Exercises 685	
	Bibliographic Notes 687	
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	
	Bibliography 703	

Index 745