## **Contents**

Pr	Preface					
Ed	ditor B	iograph	ies	xxiii		
Co	Contributors					
1	An I	An Introduction to Cluster Analysis				
	Char	и С. Agg	arwal			
	1.1	Introdu	action	. 2		
	1.2	Comm	on Techniques Used in Cluster Analysis	. 3		
		1.2.1	Feature Selection Methods	. 4		
		1.2.2	Probabilistic and Generative Models	. 4		
		1.2.3	Distance-Based Algorithms	. 5		
		1.2.4	Density- and Grid-Based Methods	. 7		
		1.2.5	Leveraging Dimensionality Reduction Methods	. 8		
			1.2.5.1 Generative Models for Dimensionality Reduction	. 8		
			1.2.5.2 Matrix Factorization and Co-Clustering	. 8		
			1.2.5.3 Spectral Methods	. 10		
		1.2.6	The High Dimensional Scenario	. 11		
		1.2.7	Scalable Techniques for Cluster Analysis	. 13		
			1.2.7.1 I/O Issues in Database Management	. 13		
			1.2.7.2 Streaming Algorithms	. 14		
			1.2.7.3 The Big Data Framework	. 14		
	1.3	Data T	ypes Studied in Cluster Analysis	. 15		
		1.3.1	Clustering Categorical Data	. 15		
		1.3.2	Clustering Text Data	. 16		
		1.3.3	Clustering Multimedia Data	. 16		
		1.3.4	Clustering Time-Series Data	. 17		
		1.3.5	Clustering Discrete Sequences			
		1.3.6	Clustering Network Data	. 18		
		1.3.7	Clustering Uncertain Data	. 19		
	1.4	Insight	ts Gained from Different Variations of Cluster Analysis	. 19		
		1.4.1	Visual Insights	. 20		
		1.4.2	Supervised Insights	. 20		
		1.4.3	Multiview and Ensemble-Based Insights			
		1.4.4	Validation-Based Insights			
	1.5	Discus	sion and Conclusions	. 22		

viii Contents

2	Featu	ıre Selec	tion for C	lustering: A Review	29
	Salen	ı Alelyan	i, Jiliang T	Tang, and Huan Liu	
	2.1	Introdu	ction		30
		2.1.1		stering	32
		2.1.2		Selection	32
		2.1.3		Selection for Clustering	33
			2.1.3.1	Filter Model	34
			2.1.3.2	Wrapper Model	35
			2.1.3.3	Hybrid Model	35
	2.2	Feature		for Clustering	35
	2.2	2.2.1		ms for Generic Data	36
		2.2.1	2.2.1.1	Spectral Feature Selection (SPEC)	36
			2.2.1.2	Laplacian Score (LS)	36
			2.2.1.3	Feature Selection for Sparse Clustering	37
			2.2.1.4	Localized Feature Selection Based on Scatter Separability	51
			2.2.1.⊤	(LFSBSS)	38
			2.2.1.5	Multicluster Feature Selection (MCFS)	39
			2.2.1.6	Feature Weighting <i>k</i> -Means	40
		2.2.2		ms for Text Data	41
		2.2.2	2.2.2.1		41
			2.2.2.1	Term Frequency (TF)	42
			2.2.2.3	Inverse Document Frequency (IDF)	42
				Term Frequency-Inverse Document Frequency (TF-IDF)	
			2.2.2.4	Chi Square Statistic	42 44
			2.2.2.5	Frequent Term-Based Text Clustering	
		2.2.2	2.2.2.6	Frequent Term Sequence	45
		2.2.3	_	ms for Streaming Data	47
			2.2.3.1	Text Stream Clustering Based on Adaptive Feature Selection	47
			2222	(TSC-AFS)	47
		2.2.4	2.2.3.2	High-Dimensional Projected Stream Clustering (HPStream)	48
		2.2.4	_	ms for Linked Data	50
			2.2.4.1	Challenges and Opportunities	50
			2.2.4.2	LUFS: An Unsupervised Feature Selection Framework for	
			• • • • •	Linked Data	51
			2.2.4.3	Conclusion and Future Work for Linked Data	52
	2.3			Challenges	53
		2.3.1		cken or the Egg Dilemma	53
		2.3.2		election: $K$ and $l$	54
		2.3.3		ity	54
		2.3.4	Stability		55
•	ъ .	1 -1- 4-	<b>N</b>		(1
3				r Clustering	61
			and Jiawe		
	3.1				61
	3.2				62
		3.2.1		W	62
		3.2.2		n Mixture Model	64
		3.2.3		li Mixture Model	67
		3.2.4		election Criteria	68
	3.3	•	_	d Its Variations	69
		3.3.1		eral EM Algorithm	69
		3.3.2	Mixture	Models Revisited	73

Contents	13
Contents	11

		3.3.3	8	75
		3.3.4		7 <i>6</i>
	3.4		1	76
		3.4.1	•	77
		3.4.2		79
	a =	3.4.3		81
	3.5	Conclus	sions and Summary	81
4		-	0 0	87
			eddy and Bhanukiran Vinzamuri	
	4.1			88
	4.2		6 6	89
		4.2.1	8	89
		4.2.2	1	9(
		4.2.3	8	9]
			1	9]
			$\mathcal{E}$	92
		4.2.4		93
			$\mathcal{E}$	93
				94
			- <b>6</b>	94
			3	95
			$oldsymbol{arepsilon}$	95
			$\mathcal{E}$	96
			$\mathcal{E}$	97
			- 6	97
			$\mathcal{E}$	98
			$\mathcal{E}$	98
		405	$\mathcal{C}$	99
	4.2	4.2.5	6	00
	4.3			00
		4.3.1	ee e	01
			e i	01
			4.3.1.2 Group Averaged and Centroid Agglomerative Clustering 10	
			4.3.1.3 Ward's Criterion	
			4.3.1.4 Agglomerative Hierarchical Clustering Algorithm	
		422	4.3.1.5 Lance–Williams Dissimilarity Update Formula 10	
		4.3.2	$\mathcal{C}$	04
			$\mathcal{E}$	04
			8 8	05
		422		05
	4.4	4.3.3	8 8	06
	4.4	Discuss	ion and Summary	06
5	Densi	ity-Based	Clustering 1	<b>1</b> 1
	Marti	n Ester		
	5.1	Introduc	ction	11
	5.2	DBSCA	N	13
	5.3	DENCL	UE 1	15
	5.4	OPTICS	S	16
	5.5	Other A	lgorithms	16

x Contents

	5.6 5.7 5.8	Clustering N	ustering	120
	5.9	Conclusion		124
6	Grid-	Based Cluste	ring	127
	Wei C	heng, Wei Wai	ng, and Sandra Batista	
	6.1	Introduction		128
	6.2		l Algorithms	
		6.2.1 Ear	liest Approaches: GRIDCLUS and BANG	131
		6.2.2 STI	NG and STING+: The Statistical Information Grid Approach	132
		6.2.3 Way	veCluster: Wavelets in Grid-Based Clustering	134
	6.3		id-Based Algorithms	135
			IR: Adaptive Mesh Refinement Clustering	135
	6.4	,	g Grid-Based Algorithms	
			GC: New Shifting Grid Clustering Algorithm	136
			CC: Adaptable Deflect and Conquer Clustering	137
			GC: Axis-Shifted Grid-Clustering	137
			ILC: Grid-Based Density-IsoLine Clustering Algorithm	
	6.5		sional Algorithms	139
			IQUE: The Classical High-Dimensional Algorithm	139
			iants of CLIQUE	140
			2.1 ENCLUS: Entropy-Based Approach	
			2.2 MAFIA: Adaptive Grids in High Dimensions	
			tiGrid: Density-Based Optimal Grid Partitioning	141
			iants of the OptiGrid Approach	143
			4.1 O-Cluster: A Scalable Approach	
			4.2 CBF: Cell-Based Filtering	
	6.6	Conclusions	and Summary	145
7	Nonn	egative Matri	ix Factorizations for Clustering: A Survey	149
	Tao L	i and Chris Di	ing	
	7.1	Introduction		150
		7.1.1 Bac	kground	150
		7.1.2 NM	IF Formulations	151
	7.2	NMF for Clu	stering: Theoretical Foundations	151
		7.2.1 NM	IF and <i>K</i> -Means Clustering	151
			IF and Probabilistic Latent Semantic Indexing	152
		7.2.3 NM	IF and Kernel K-Means and Spectral Clustering	152
		7.2.4 NM	IF Boundedness Theorem	153
	7.3	NMF Cluster	ring Capabilities	153
		7.3.1 Exa	amples	153
		7.3.2 Ana	alysis	153
	7.4	NMF Algori		155
			oduction	155
		_	orithm Development	155
			ctical Issues in NMF Algorithms	156
		7.4.		156
		7.4.	11 8	156
		7.4.	3	157
		7.4.	3.4 Scalability	157

*Contents* xi

	7.5	NMF Related Factorizations	158
	7.6	NMF for Clustering: Extensions	161
		7.6.1 Co-Clustering	
		7.6.2 Semisupervised Clustering	
		7.6.3 Semisupervised Co-Clustering	162
		7.6.4 Consensus Clustering	
		7.6.5 Graph Clustering	
		7.6.6 Other Clustering Extensions	
	7.7	Conclusions	
	7.7	Conclusions	103
8	Spect	al Clustering	177
	Jialu .	iu and Jiawei Han	
	8.1	Introduction	177
	8.2	Similarity Graph	179
	8.3	Unnormalized Spectral Clustering	180
		8.3.1 Notation	180
		8.3.2 Unnormalized Graph Laplacian	180
		8.3.3 Spectrum Analysis	181
		8.3.4 Unnormalized Spectral Clustering Algorithm	
	8.4	Normalized Spectral Clustering	182
	0.4	8.4.1 Normalized Graph Laplacian	183
		8.4.2 Spectrum Analysis	184
	0.5	8 8	
	8.5	Graph Cut View	185
		8.5.1 Ratio Cut Relaxation	186
	0.6	8.5.2 Normalized Cut Relaxation	187
	8.6	Random Walks View	
	8.7	Connection to Laplacian Eigenmap	
	8.8	Connection to Kernel <i>k</i> -Means and Nonnegative Matrix Factorization	191
	8.9	Large Scale Spectral Clustering	
	8.10	Further Reading	194
9	Clust	ring High-Dimensional Data	201
		Zimek	
	9.1		201
	9.2	The "Curse of Dimensionality"	
	> · <b>-</b>	9.2.1 Different Aspects of the "Curse"	
		9.2.2 Consequences	206
	9.3	Clustering Tasks in Subspaces of High-Dimensional Data	206
	7.5	9.3.1 Categories of Subspaces	
		9.3.1.1 Axis-Parallel Subspaces	
		9.3.1.2 Arbitrarily Oriented Subspaces	
		J 1	
		9.3.1.3 Special Cases	
	0.4	9.3.2 Search Spaces for the Clustering Problem	
	9.4	Fundamental Algorithmic Ideas	
		9.4.1 Clustering in Axis-Parallel Subspaces	
		9.4.1.1 Cluster Model	208
		9.4.1.2 Basic Techniques	
		9.4.1.3 Clustering Algorithms	
		9.4.2 Clustering in Arbitrarily Oriented Subspaces	
		9.4.2.1 Cluster Model	215

xii Contents

		9.4.2.2 Basic Techniques and Example Algorithms	216
	9.5	Open Questions and Current Research Directions	218
	9.6	Conclusion	19
10	A Sur	ey of Stream Clustering Algorithms	231
	Charu	C. Aggarwal	
	10.1	ntroduction	231
	10.2	Methods Based on Partitioning Representatives	233
		0.2.1 The STREAM Algorithm	233
			235
			235
		10.2.2.2 Pyramidal Time Frame	236
		10.2.2.3 Online Clustering with CluStream	237
	10.3		239
			40
			41
			41
			42
	10.4		243
	10.5		43
			244
			244
	10.6	· · · · · · · · · · · · · · · · · · ·	45
			45
		· · · · · · · · · · · · · · · · · · ·	45
			46
	10.7		49
	10.8		52
			253
			253
			254
	10.9	E C	254
11	D:~ D		259
11	_		137
	0	ang Tong and U Kang	50
	11.1		259
	11.2	$\epsilon$	260
			260
		υ ο ο ο ο ο ο ο ο ο ο ο ο ο ο ο ο ο ο ο	61
	11.2	$\mathcal{C}$	263
	11.3		263
		$\mathcal{L}$	264
	11 4	$\mathbf{j}$	266
	11.4	$\mathcal{E}$	268
			268
		•	269
			269
		1	270
		$\varepsilon$ 1	271
			72
	11.5	Conclusion	274

*Contents* xiii

12	Cluste	ering Ca	tegorical Data	277
	Bill A	ndreopou	ulos	
	12.1	Introduc	ction	278
	12.2	Goals of	f Categorical Clustering	279
		12.2.1	Clustering Road Map	280
	12.3	Similari	ty Measures for Categorical Data	
		12.3.1	The Hamming Distance in Categorical and Binary Data	
		12.3.2	Probabilistic Measures	
		12.3.3	Information-Theoretic Measures	283
		12.3.4	Context-Based Similarity Measures	284
	12.4	Descrip	tions of Algorithms	
		12.4.1	Partition-Based Clustering	
			12.4.1.1 <i>k</i> -Modes	
			12.4.1.2 <i>k</i> -Prototypes (Mixed Categorical and Numerical)	
			12.4.1.3 Fuzzy <i>k</i> -Modes	
			12.4.1.4 Squeezer	
			12.4.1.5 COOLCAT	
		12.4.2	Hierarchical Clustering	
			12.4.2.1 ROCK	
			12.4.2.2 COBWEB	
			12.4.2.3 LIMBO	
		12.4.3	Density-Based Clustering	
			12.4.3.1 Projected (Subspace) Clustering	
			12.4.3.2 CACTUS	
			12.4.3.3 CLICKS	
			12.4.3.4 STIRR	
			12.4.3.5 CLOPE	
			12.4.3.6 HIERDENC: Hierarchical Density-Based Clustering	
			12.4.3.7 MULIC: Multiple Layer Incremental Clustering	
		12.4.4	Model-Based Clustering	
			12.4.4.1 BILCOM Empirical Bayesian (Mixed Categorical and Numer-	
			ical)	296
			12.4.4.2 AutoClass (Mixed Categorical and Numerical)	
			12.4.4.3 SVM Clustering (Mixed Categorical and Numerical)	
	12.5	Conclus		298
13	Docui	ment Clu	stering: The Next Frontier	305
	David		tasiu, Andrea Tagarelli, and George Karypis	
	13.1	Introduc	ction	306
	13.2	Modelin	ng a Document	306
		13.2.1	Preliminaries	306
		13.2.2	The Vector Space Model	307
		13.2.3	Alternate Document Models	309
		13.2.4	Dimensionality Reduction for Text	309
		13.2.5	Characterizing Extremes	310
	13.3		Purpose Document Clustering	311
		13.3.1	Similarity/Dissimilarity-Based Algorithms	311
		13.3.2	Density-Based Algorithms	312
		13.3.3	Adjacency-Based Algorithms	313
		13.3.4	Generative Algorithms	313
	13.4	Clusteri	ng Long Documents	315

xiv Contents

		13.4.1 13.4.2 13.4.3	Document Segmentation	317
	13.5	Clusteri	ng Short Documents	
		13.5.1	General Methods for Short Document Clustering	323
		13.5.2	Clustering with Knowledge Infusion	324
		13.5.3	Clustering Web Snippets	325
		13.5.4	Clustering Microblogs	326
	13.6	Conclus	ion	328
14	Clusto	ering Mu	ıltimedia Data	339
	Shen-	Fu Tsai, (	Guo-Jun Qi, Shiyu Chang, Min-Hsuan Tsai, and Thomas S. Huang	
	14.1	Introduc	ction	340
	14.2	Clusteri	ng with Image Data	340
		14.2.1	Visual Words Learning	
		14.2.2	Face Clustering and Annotation	342
		14.2.3	Photo Album Event Recognition	343
		14.2.4	Image Segmentation	344
		14.2.5	Large-Scale Image Classification	345
	14.3	Clusteri	ng with Video and Audio Data	
		14.3.1	Video Summarization	348
		14.3.2	Video Event Detection	349
		14.3.3	Video Story Clustering	
		14.3.4	Music Summarization	350
	14.4		ng with Multimodal Data	
	14.5	Summai	ry and Future Directions	353
15	Time-	Series D	ata Clustering	357
15			ata Clustering akos, Goce Trajcevski, Dimitrios Gunopulos, and Charu C.	357
15		rios Kotso		357
15	Dimiti	rios Kotse wal		
15	Dimiti Aggar	rios Kotse wal Introduc	akos, Goce Trajcevski, Dimitrios Gunopulos, and Charu C.	358
15	Dimita Aggar 15.1	rios Kotso wal Introduc The Div	ction	358 359 360
15	Dimite Aggar 15.1 15.2	rios Kotso wal Introduc The Div	akos, Goce Trajcevski, Dimitrios Gunopulos, and Charu C.  etion	358 359 360
15	Dimite Aggar 15.1 15.2	rios Kotso rwal Introduc The Div Online (	ction	358 359 360 361
15	Dimite Aggar 15.1 15.2	rios Kotso wal Introduc The Div Online O 15.3.1 15.3.2	akos, Goce Trajcevski, Dimitrios Gunopulos, and Charu C.  etion	358 359 360 361 362
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online O 15.3.1 15.3.2	ction	358 359 360 361 362 363
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari	ction	358 359 360 361 362 363
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari	ction	358 359 360 361 362 363 363
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari	tion	358 359 360 361 362 363 363 363
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari	tion	358 359 360 361 362 363 363 364
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari	tion	358 359 360 361 362 363 363 364 365
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari 15.4.1	tion	358 359 360 361 362 363 363 364 365 365
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari 15.4.1	tion	358 359 360 361 362 363 363 364 365 365 366
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari 15.4.1	ction	358 359 360 361 362 363 363 364 365 366 366
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari 15.4.1	tion	358 359 360 361 362 363 363 364 365 366 366 366
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari 15.4.1	ction	358 359 360 361 362 363 363 365 365 366 367 368
15	Dimitst Aggar 15.1 15.2 15.3	rios Kotso wal Introduc The Div Online C 15.3.1 15.3.2 Similari 15.4.1	etion	358 359 360 361 362 363 363 364 365 366 366 368 368
15	Dimits Aggar 15.1 15.2 15.3 15.4	rios Kotso wal Introduc The Div Online C 15.3.1 15.3.2 Similari 15.4.1	tion	358 359 360 361 362 363 363 365 365 366 367 368 368 368 368 369 370
15	Dimits Aggar 15.1 15.2 15.3 15.4	rios Kotso wal Introduc The Div Online ( 15.3.1 15.3.2 Similari 15.4.1	akos, Goce Trajcevski, Dimitrios Gunopulos, and Charu C.  etion  erse Formulations for Time-Series Clustering Correlation-Based Clustering Selective Muscles and Related Methods Sensor Selection Algorithms for Correlation Clustering ty and Distance Measures Univariate Distance Measures  15.4.1.1 $L_p$ Distance 15.4.1.2 Dynamic Time Warping Distance 15.4.1.3 EDIT Distance 15.4.1.4 Longest Common Subsequence Multivariate Distance Measures 15.4.2.1 Multidimensional $L_p$ Distance 15.4.2.2 Multidimensional DTW 15.4.2.3 Multidimensional LCSS 15.4.2.4 Multidimensional Edit Distance 15.4.2.5 Multidimensional Subsequence Matching Based Time-Series Clustering Techniques	358 359 360 361 362 363 363 365 365 366 367 368 368 368 368 369 370

Contents xv

		15.5.4	Trajectory Clustering	372
	15.6		eries Clustering Applications	
	15.7		sions	
16	Cluste	ering Ric	ological Data	381
LU		_		301
	16.1		eddy, Mohammad Al Hasan, and Mohammed J. Zaki	201
	16.1		ng Microarray Data	
	10.2	16.2.1	•	383
		16.2.1	Categorization of Algorithms	
		16.2.3	Standard Clustering Algorithms	
		10.2.3	16.2.3.1 Hierarchical Clustering	
			16.2.3.2 Probabilistic Clustering	386
			16.2.3.3 Graph-Theoretic Clustering	386
				387
			16.2.3.4 Self-Organizing Maps	387
		16.2.4	<u> </u>	388
		10.2.4	Biclustering	389
			16.2.4.1 Types and Structures of Biclusters	
			16.2.4.2 Biclustering Algorithms	391
		16.2.5	1	391
			Triclustering	
		16.2.6 16.2.7	Time-Series Gene Expression Data Clustering	392
	16.2			393
	16.3		6 6	394 394
		16.3.1	Characteristics of PPI Network Data	
		16.3.2	Network Clustering Algorithms	394
			16.3.2.1 Molecular Complex Detection	
			16.3.2.2 Markov Clustering	
			$\epsilon$	395
			1	395
			16.3.2.5 Ensemble Clustering	
		1600	16.3.2.6 Other Clustering Methods	
	164	16.3.3	Cluster Validation and Challenges	
	16.4	_	cal Sequence Clustering	397
		16.4.1	1	397
			5	398
			16.4.1.2 Keyword-Based Similarity	398
			16.4.1.3 Kernel-Based Similarity	399
		16.10	16.4.1.4 Model-Based Similarity	399
		16.4.2	Sequence Clustering Algorithms	399
			16.4.2.1 Subsequence-Based Clustering	399
			16.4.2.2 Graph-Based Clustering	400
			16.4.2.3 Probabilistic Models	402
			16.4.2.4 Suffix Tree and Suffix Array-Based Method	403
	16.5		e Packages	403
	16.6	Discuss	ion and Summary	405

xvi Contents

17		8	415					
	Srinivasan Parthasarathy and S M Faisal							
	17.1		416					
	17.2	Background and Nomenclature	417					
	17.3	Problem Definition	417					
	17.4	Common Evaluation Criteria	418					
	17.5	Partitioning with Geometric Information	419					
		17.5.1 Coordinate Bisection	419					
		17.5.2 Inertial Bisection	419					
		17.5.3 Geometric Partitioning	420					
	17.6	Graph Growing and Greedy Algorithms	421					
		17.6.1 Kernighan-Lin Algorithm	422					
	17.7	Agglomerative and Divisive Clustering	423					
	17.8	Spectral Clustering	424					
		17.8.1 Similarity Graphs	425					
		17.8.2 Types of Similarity Graphs	425					
		17.8.3 Graph Laplacians	426					
			426					
			427					
		17.8.4 Spectral Clustering Algorithms	427					
	17.9	*	428					
		17.9.1 Regularized MCL (RMCL): Improvement over MCL	429					
	17.10	Multilevel Partitioning	430					
	17.11	Local Partitioning Algorithms	432					
			433					
			435					
			435					
		1 1	436					
			437					
		17.13.4 Directed Networks	438					
			439					
		· · · · · · · · · · · · · · · · · · ·	440					
		11 6	442					
	17.14	Conclusion	443					
18	A Sur	vey of Uncertain Data Clustering Algorithms	457					
		a C. Aggarwal						
	18.1		457					
	18.2	8	459					
	18.3	5 6	460					
		$\mathcal{C}$	460					
		$\mathcal{C}$	461					
	18.4	Partitional Clustering Algorithms	462					
		$\mathcal{E}$	462					
		$\mathcal{E}$	463					
		18.4.3 Clustering Uncertain Data with Voronoi Diagrams	464					
			464					
		18.4.5 Speeding Up Distance Computations	465					
	18.5	$\mathcal{C}$	466					
		$\mathcal{C}$	466					
			471					

			Contents	xvii
		18.5.3	Enhancements to Stream Clustering	471
	18.6		ing Uncertain Data in High Dimensionality	
	10.0	18.6.1	Subspace Clustering of Uncertain Data	
		18.6.2	UPStream: Projected Clustering of Uncertain Data Streams	
	18.7		ing with the Possible Worlds Model	
	18.8		ing Uncertain Graphs	
	18.9		sions and Summary	
	10.7	Conclus	sions and Summary	7/0
19		-	isual and Interactive Clustering	483
		nder Hin	O .	
	19.1		ction	
	19.2		Visual and Interactive Clustering	
		19.2.1	Scatterplots	
		19.2.2	Parallel Coordinates	
		19.2.3	Discussion	491
	19.3	Visual I	Interactive Steering of Clustering	491
		19.3.1	Visual Assessment of Convergence of Clustering Algorithm	491
		19.3.2	Interactive Hierarchical Clustering	492
		19.3.3	Visual Clustering with SOMs	494
		19.3.4	Discussion	494
	19.4	Interact	ive Comparison and Combination of Clusterings	495
		19.4.1	Space of Clusterings	495
		19.4.2	Visualization	
		19.4.3	Discussion	497
	19.5	Visualiz	zation of Clusters for Sense-Making	497
	19.6		ry	
20	Somic	unorvice	ed Clustering	505
20		-		303
	20.1		ic and Arindam Banerjee	504
			ction	
	20.2		ing with Pointwise and Pairwise Semisupervision	
			Semisupervised Clustering Based on Seeding	
		20.2.2	Semisupervised Clustering Based on Pairwise Constraints	
		20.2.3	Active Learning for Semisupervised Clustering	
		20.2.4	Semisupervised Clustering Based on User Feedback	
	20.0	20.2.5	Semisupervised Clustering Based on Nonnegative Matrix Factorization.	
	20.3		pervised Graph Cuts	
		20.3.1	Semisupervised Unnormalized Cut	
		20.3.2	Semisupervised Ratio Cut	
		20.3.3	Semisupervised Normalized Cut	
	20.4		ed View of Label Propagation	
		20.4.1	Generalized Label Propagation	
		20.4.2	Gaussian Fields	
		20.4.3	Tikhonov Regularization (TIKREG)	518
		20.4.4	Local and Global Consistency	
		20.4.5	Related Methods	
			20.4.5.1 Cluster Kernels	519
			20.4.5.2 Gaussian Random Walks EM (GWEM)	519
			20.4.5.3 Linear Neighborhood Propagation	520
		20.4.6	Label Propagation and Green's Function	521
		20 4 7	Label Propagation and Semisupervised Graph Cuts	521

xviii Contents

	20.5	_	pervised Embedding	521	
		20.5.1	Nonlinear Manifold Embedding	522	
		20.5.2	Semisupervised Embedding	522	
			20.5.2.1 Unconstrained Semisupervised Embedding		
			20.5.2.2 Constrained Semisupervised Embedding	523	
	20.6	Compar	ative Experimental Analysis	524	
		20.6.1	Experimental Results	524	
		20.6.2	Semisupervised Embedding Methods	529	
	20.7	Conclus	sions	530	
21	Alteri	native Cl	ustering Analysis: A Review	535	
	James	Bailey			
	21.1	Introduc	ction	535	
	21.2	Technic	al Preliminaries	537	
	21.3	Multiple	e Clustering Analysis Using Alternative Clusterings	538	
		$21.3.\overline{1}$	Alternative Clustering Algorithms: A Taxonomy	538	
		21.3.2	Unguided Generation	539	
			21.3.2.1 Naive	539	
			21.3.2.2 Meta Clustering	539	
			21.3.2.3 Eigenvectors of the Laplacian Matrix	540	
			21.3.2.4 Decorrelated <i>k</i> -Means and Convolutional EM	540	
			21.3.2.5 CAMI	540	
		21.3.3	Guided Generation with Constraints	541	
			21.3.3.1 COALA	541	
			21.3.3.2 Constrained Optimization Approach	541	
			21.3.3.3 MAXIMUS	542	
		21.3.4	Orthogonal Transformation Approaches	543	
			21.3.4.1 Orthogonal Views	543	
			21.3.4.2 ADFT		
		21.3.5	Information Theoretic	544	
		21.5.5	21.3.5.1 Conditional Information Bottleneck (CIB)	544	
			21.3.5.2 Conditional Ensemble Clustering	544	
			21.3.5.3 NACI		
			21.3.5.4 mSC		
	21.4	Connect	tions to Multiview Clustering and Subspace Clustering	545	
	21.5		Research Issues	547	
	21.6		ry	547	
				541	
22			nbles: Theory and Applications	551	
			a and Ayan Acharya		
	22.1		ction	551	
	22.2		ster Ensemble Problem		
	22.3		ing Similarity Between Clustering Solutions	555 558	
	22.4	$\mathcal{E}$			
		22.4.1	Probabilistic Approaches to Cluster Ensembles	558	
			22.4.1.1 A Mixture Model for Cluster Ensembles (MMCE)	558	
			22.4.1.2 Bayesian Cluster Ensembles (BCE)	558	
			22.4.1.3 Nonparametric Bayesian Cluster Ensembles (NPBCE)	559	
		22.4.2	Pairwise Similarity-Based Approaches	560	
			22.4.2.1 Methods Based on Ensemble Co-Association Matrix	560	

*Contents* xix

22.4.3. Direct Approaches Using Cluster Labels         56.           22.4.3.1 Camulative Voting         56.           22.5. Applications of Consensus Clustering         56.           22.5.1 Gene Expression Data Analysis         56.           22.5.2 Image Segmentation         56.           22.6 Concluding Remarks         56.           23 Clustering Validation Measures         57.           23.1 Introduction         57.           23.2. External Clustering Validation Measures         57.           23.2.1 An Overview of External Clustering Validation Measures         57.           23.2.2.1 External Clustering Validation Measures         57.           23.2.2.2 Defective Validation Measures         57.           23.2.2.3 The Cluster Validation Results         57.           23.2.2.3 The Cluster Validation Results         57.           23.2.2.4 The Issues with the Defective Measures         57.           23.2.3.3 Normalization         57.           23.2.3.3 Normalizing the Measures         57.           23.2.3.3 The Effect of Normalization         58.           23.2.3.1 The Consistency Between Measures         57.           23.2.2.4 Properties of Measures         58.           23.2.4.1 The Consistency Between Measures         58.           23.3.2.1 The Impact of Normalization				22.4.2.2	Relating Consensus Clustering to Other Optimization Formulations								
22.4.3.1 Graph Partitioning         56.           22.5 Applications of Consensus Clustering         56.           22.5.1 Gene Expression Data Analysis         56.           22.5.2 Image Segmentation         56.           22.5.2 Concluding Remarks         56.           23 Clustering Validation Measures         57.           23.1 Introduction         57.           23.2.1 An Overview of External Clustering Validation Measures         57.           23.2.1 An Overview of External Clustering Validation Measures         57.           23.2.2.1 K-Means: The Uniform Effect         57.           23.2.2.2 Defective Validation Measures         57.           23.2.2.3 The Cluster Validation Results         57.           23.2.2.3 The Cluster Validation Results         57.           23.2.2.3 The Cluster Validation Results         57.           23.2.3.1 Normalization         57.           23.2.3.2 The DCV Criterion         58.           23.2.3.3 The Effect of Normalization         57.           23.2.3.4 Measure Properties         58.           23.2.4.1 The Consistency Between Measures         58.           23.2.4.2 Properties of Measures         58.           23.3.1 Internal Clustering Validation Measures         58.           23.3.2 Understanding of Internal Clustering Validation Meas			22 / 3	Direct Ar									
22.43.2 Cumulative Voting         56           22.5 Applications of Consensus Clustering         56           22.5.1 Gene Expression Data Analysis         56           22.5.2 Image Segmentation         56           22.6 Concluding Remarks         56           23 Clustering Validation Measures         57           23 Clustering Validation Measures         57           23.1 Introduction         57           23.2.1 An Overview of External Clustering Validation Measures         57           23.2.2.1 An Overview of External Clustering Validation Measures         57           23.2.2.1 K-Means: The Uniform Effect         57           23.2.2.2 A Necessary Selection Criterion         57           23.2.2.3 The Cluster Validation Results         57           23.2.2.3 The Cluster Validation Results         57           23.2.3.1 Normalization         57           23.2.3.2 The DCV Criterion         58           23.2.3.3 The Effect of Normalization         58           23.2.4.1 The Consistency Between Measures         58           23.2.4.2 Properties of Measures         58           23.2.4.2 Properties of Measures         58           23.3.3.1 An Overview of Internal Clustering Validation Measures         58           23.3.2.2 Properties of Measures         58 <th></th> <td></td> <td>22.4.3</td> <td></td> <td></td>			22.4.3										
22.5. Applications of Consensus Clustering         56-22.5.1 Gene Expression Data Analysis         56-22.5.2 Image Segmentation         56-22.6 Concluding Remarks         57-23.2 External Clustering Validation Measures         57-23.2 External Cluster Validation Results         58-23.2 External Cluster Validation Results         58-23.2 External Cluster Validation Res													
22.5.1   Gene Expression Data Analysis   566   22.5.2   Image Segmentation   566   22.5.2   Image Segmentation   566   22.6   Concluding Remarks   560   561   562   5		22.5	A1:										
22.5.2 Image Segmentation       566         22.6 Concluding Remarks       566         23 Clustering Validation Measures       571         Hui Xiong and Zhongmou Li       572         23.1 Introduction       577         23.2. External Clustering Validation Measures       577         23.2.1 An Overview of External Clustering Validation Measures       572         23.2.2.1 K-Means: The Uniform Effect       572         23.2.2.2 A Necessary Selection Criterion       576         23.2.2.3 The Cluster Validation Results       577         23.2.2.3 The Inproving the Defective Measures       577         23.2.2.3 Improving the Defective Measures       577         23.2.3.1 Normalization       57         23.2.3.2 The DV Criterion       58         23.2.3.3 The Effect of Normalization       58         23.2.4.4 Measure Properties       58         23.2.4.2 Properties of Measures       58         23.2.4.2 Properties of Measures       58         23.2.4.3 Discussions       58         23.3.1 Internal Clustering Validation Measures       58         23.3.2.2 The Impact of Monotonicity       59         23.3.2.2 The Impact of Subclusters       59         23.3.2.3 The Impact of Subclusters       59         23.3.2.3 The		22.5											
22.6 Concluding Remarks         566           23 Clustering Validation Measures         571           Hui Xiong and Zhongmou Li         572           23.1 Introduction         577           23.2 External Clustering Validation Measures         572           23.2.1 An Overview of External Clustering Validation Measures         572           23.2.2.1 K-Means: The Uniform Effect         573           23.2.2.2 A Necessary Selection Criterion         576           23.2.2.3 The Cluster Validation Results         576           23.2.2.4 The Issues with the Defective Measures         577           23.2.2.2 Improving the Defective Measures         577           23.2.3.1 Normalization         577           23.2.3.2 The DCV Criterion         58           23.2.3.3 The Effect of Normalization         58           23.2.4.1 The Consistency Between Measures         58           23.2.4.2 Properties of Measures         58           23.2.4.3 Discussions         58           23.3.1 An Overview of Internal Clustering Validation Measures         58           23.3.2 Understanding of Internal Clustering Validation Measures         58           23.3.2.1 The Impact of Monotonicity         59           23.3.2.2 The Impact of Skewed Distributions         59           23.3.2.3 The Impact of Skewed													
23 Clustering Validation Measures         571           Hui Xiong and Zhongmou Li         572           23.1 Introduction         572           23.2 External Clustering Validation Measures         573           23.2.1 An Overview of External Clustering Validation Measures         574           23.2.2.2 Defective Validation Measures         575           23.2.2.2. A Necessary Selection Criterion         576           23.2.2.2. A Necessary Selection Criterion         576           23.2.2.2. The Cluster Validation Results         577           23.2.2.2. Improving the Defective Measures         577           23.2.2.1 Normalization         577           23.2.3.1 Normalization the Measures         578           23.2.3.2 The DCV Criterion         588           23.2.3.3 The Effect of Normalization         58           23.2.4.1 The Consistency Between Measures         58           23.2.4.2 Properties of Measures         58           23.2.4.3 Discussions         58           23.3.1 An Overview of Internal Clustering Validation Measures         58           23.3.1 An Overview of Internal Clustering Validation Measures         59           23.3.2.1 The Impact of Noise         59           23.3.2.2 The Impact of Subclusters         59           23.3.2.3 The Impact of Subclustering		22.6		_	<del>-</del>								
Hui Xiong and Zhongmou Li       23.1 Introduction       57.         23.2 External Clustering Validation Measures       57.         23.2.1 An Overview of External Clustering Validation Measures       57.         23.2.2.2 Defective Validation Measures       57.         23.2.2.3 The Cluster Validation Cresults       57.         23.2.2.2 A Necessary Selection Criterion       57.         23.2.2.3 The Cluster Validation Results       57.         23.2.2.4 The Issues with the Defective Measures       57.         23.2.3.1 Normalization       57.         23.2.3.3 Informalization the Measures       57.         23.2.3.3 The Effect of Normalization       58.         23.2.4.1 The Consistency Between Measures       58.         23.2.4.2 Properties of Measures       58.         23.2.4.3 Discussions       58.         23.3.1 An Overview of Internal Clustering Validation Measures       58.         23.3.2 Understanding of Internal Clustering Validation Measures       58.         23.3.2.2 The Impact of Monotonicity       59.         23.3.2.3 The Impact of Skewed Distributions       59.         23.3.2.5 The Impact of Skewed Distributions       59.         23.3.2.6 The Impact of Skewed Distributions       59.         23.3.2.7 The Impact of Skewed Distributions       59.		22.6	Conclud	ling Remar	ks								
23.1 Introduction       57.         23.2 External Clustering Validation Measures       57.         23.2.1 An Overview of External Clustering Validation Measures       57.         23.2.2.2 Defective Validation Measures       57.         23.2.2.1 K-Means: The Uniform Effect       57.         23.2.2.2.3 The Cluster Validation Results       57.         23.2.2.3 The Cluster Validation Results       57.         23.2.2.4 The Issues with the Defective Measures       57.         23.2.3.1 Normalization       57.         23.2.3.2 The DCV Criterion       58.         23.2.3.3 The Effect of Normalization       58.         23.2.4.1 The Consistency Between Measures       58.         23.2.4.2 Properties of Measures       58.         23.2.4.3 Discussions       58.         23.3 Internal Clustering Validation Measures       58.         23.3.1 An Overview of Internal Clustering Validation Measures       58.         23.3.2.1 The Impact of Monotonicity       59.         23.3.2.2 The Impact of Obosie       59.         23.3.2.3 The Impact of Skewed Distributions       59.         23.3.2.5 The Impact of Skewed Distributions       59.         23.3.2.6 The Impact of Skewed Distributions       59.         23.3.2.7 The Impact of Skewed Distributions       59. <t< th=""><th>23</th><th colspan="12">Clustering Validation Measures 57</th></t<>	23	Clustering Validation Measures 57											
23.2 External Clustering Validation Measures       57.         23.2.1 An Overview of External Clustering Validation Measures       57.         23.2.2 Defective Validation Measures       57.         23.2.2.1 K-Means: The Uniform Effect       57.         23.2.2.2 A Necessary Selection Criterion       57.         23.2.2.3 The Cluster Validation Results       57.         23.2.2.4 The Issues with the Defective Measures       57.         23.2.2.5 Improving the Defective Measures       57.         23.2.3.1 Normalizing the Measures       57.         23.2.3.2 The DCV Criterion       58.         23.2.3.3 The Effect of Normalization       58.         23.2.4.1 The Consistency Between Measures       58.         23.2.4.2 Properties of Measures       58.         23.2.4.3 Discussions       58.         23.3.1 An Overview of Internal Clustering Validation Measures       58.         23.3.2 Understanding of Internal Clustering Validation Measures       58.         23.3.2 Understanding of Internal Clustering Validation Measures       58.         23.3.2.2 The Impact of Monotonicity       59.         23.3.2.3 The Impact of Subclusters       59.         23.3.2.4 The Impact of Subclusters       59.         23.3.2.5 The Impact of Skewed Distributions       59.         23.3.3 Properties		Ниі Х	iong and	Zhongmou	ı Li								
23.2.1       An Overview of External Clustering Validation Measures       574         23.2.2.1       Defective Validation Measures       575         23.2.2.1       K-Means: The Uniform Effect       575         23.2.2.2.3       A Necessary Selection Criterion       576         23.2.2.3       The Cluster Validation Results       577         23.2.2.5       Improving the Defective Measures       577         23.2.3.1       Normalization       577         23.2.3.2       The DCV Criterion       58         23.2.3.3       The Effect of Normalization       58         23.2.4.1       The Consistency Between Measures       58         23.2.4.2       Properties of Measures       58         23.2.4.3       Discussions       58         23.2.4.2       Properties of Measures       58         23.2.3.1       An Overview of Internal Clustering Validation Measures       58         23.3.2       1 The Impact of Monotonicity       59         23.3.2.2       The Impact of Noise       59         23.3.2.2       The Impact of Subclusters       59         23.3.2.2       The Impact of Subclusters       59         23.3.2.5       The Impact of Skewed Distributions       59         23.3.2		23.1	Introduc	ction	57								
23.2.2       Defective Validation Measures       57: 23.2.2.1 K-Means: The Uniform Effect       57: 23.2.2.2.1 K-Means: The Uniform Effect       57: 23.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.		23.2	External	l Clustering	g Validation Measures								
23.2.2       Defective Validation Measures       57: 23.2.2.1 K-Means: The Uniform Effect       57: 23.2.2.2.1 K-Means: The Uniform Effect       57: 23.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.			23.2.1	An Overv	view of External Clustering Validation Measures 57								
23.2.2.2       A Necessary Selection Criterion       576         23.2.2.3       The Cluster Validation Results       577         23.2.2.4       The Issues with the Defective Measures       577         23.2.2.5       Improving the Defective Measures       577         23.2.3       Measure Normalization       577         23.2.3.1       Normalizing the Measures       578         23.2.3.2       The DCV Criterion       58         23.2.3       The Effect of Normalization       58         23.2.4       Measure Properties       58         23.2.4.1       The Consistency Between Measures       58         23.2.4.2       Properties of Measures       58         23.2.4.3       Discussions       58         23.2.4.3       Discussions       58         23.3       Internal Clustering Validation Measures       58         23.3       1 An Overview of Internal Clustering Validation Measures       58         23.3.1       An Overview of Internal Clustering Validation Measures       58         23.3.2.1       The Impact of Monotonicity       59         23.3.2.2       The Impact of Noise       59         23.3.2.2       The Impact of Density       59         23.3.2.5       The Impac			23.2.2										
23.2.2.2       A Necessary Selection Criterion       576         23.2.2.3       The Cluster Validation Results       577         23.2.2.4       The Issues with the Defective Measures       577         23.2.2.5       Improving the Defective Measures       577         23.2.3       Measure Normalization       577         23.2.3.1       Normalizing the Measures       578         23.2.3.2       The DCV Criterion       58         23.2.3       The Effect of Normalization       58         23.2.4       Measure Properties       58         23.2.4.1       The Consistency Between Measures       58         23.2.4.2       Properties of Measures       58         23.2.4.3       Discussions       58         23.2.4.3       Discussions       58         23.3       Internal Clustering Validation Measures       58         23.3       1 An Overview of Internal Clustering Validation Measures       58         23.3.1       An Overview of Internal Clustering Validation Measures       58         23.3.2.1       The Impact of Monotonicity       59         23.3.2.2       The Impact of Noise       59         23.3.2.2       The Impact of Density       59         23.3.2.5       The Impac													
23.2.2.3 The Cluster Validation Results       576         23.2.2.4 The Issues with the Defective Measures       577         23.2.2.5 Improving the Defective Measures       577         23.2.3 Measure Normalization       577         23.2.3.1 Normalizing the Measures       578         23.2.3.2 The DCV Criterion       58         23.2.3.3 The Effect of Normalization       58         23.2.4 Measure Properties       58         23.2.4.1 The Consistency Between Measures       58         23.2.4.2 Properties of Measures       58         23.2.4.3 Discussions       58         23.3.1 An Overview of Internal Clustering Validation Measures       58         23.3.1 An Overview of Internal Clustering Validation Measures       58         23.3.2 Understanding of Internal Clustering Validation Measures       59         23.3.2.2 The Impact of Monotonicity       59         23.3.2.3 The Impact of Density       59         23.3.2.4 The Impact of Subclusters       59         23.3.2.5 The Impact of Subclusters       59         23.3.2.6 The Impact of Skewed Distributions       59         23.3.2.7 The Impact of Arbitrary Shapes       59         23.3.2.8 The Impact of Arbitrary Shapes       60         24.2 Educational Resources       60         24.2 Educati													
23.2.2.4 The Issues with the Defective Measures       577         23.2.2.5 Improving the Defective Measures       577         23.2.3.1 Mormalization       577         23.2.3.2 The DCV Criterion       58         23.2.3.3 The Effect of Normalization       58         23.2.4.4 Measure Properties       58         23.2.4.2 Properties of Measures       58         23.2.4.3 Discussions       58         23.3 Internal Clustering Validation Measures       58         23.3.1 An Overview of Internal Clustering Validation Measures       58         23.3.2 Understanding of Internal Clustering Validation Measures       59         23.3.2.1 The Impact of Monotonicity       59         23.3.2.2 The Impact of Noise       59         23.3.2.3 The Impact of Subclusters       59         23.3.2.5 The Impact of Skewed Distributions       59         23.3.2.6 The Impact of Skewed Distributions       59         23.3.3 Properties of Measures       60         23.4 Summary       60         24.2 Educational Resources for Data Clustering       60         24.2.1 Books on Data Clustering       60         24.2.2 Popular Survey Papers on Data Clustering       60         24.2.2 Popular Survey Papers on Data Clustering       60         24.3.1 Free and Open-Source Softw					· · · · · · · · · · · · · · · · · · ·								
23.2.2.5 Improving the Defective Measures       577         23.2.3.1 Measure Normalization       577         23.2.3.2 The DCV Criterion       58         23.2.3.3 The Effect of Normalization       58         23.2.4.4 Measure Properties       58         23.2.4.1 The Consistency Between Measures       58         23.2.4.2 Properties of Measures       58         23.2.4.3 Discussions       58         23.3.1 An Overview of Internal Clustering Validation Measures       58         23.3.2 Understanding of Internal Clustering Validation Measures       58         23.3.2.1 The Impact of Monotonicity       59         23.3.2.2 The Impact of Noise       59         23.3.2.3 The Impact of Subclusters       59         23.3.2.5 The Impact of Skewed Distributions       59         23.3.2.6 The Impact of Skewed Distributions       59         23.3.3 Properties of Measures       60         23.4 Summary       60         24.2 Educational Resources for Data Clustering       60         24.2.1 Books on Data Clustering       60         24.2.2 Popular Survey Papers on Data Clustering       60         24.2.2 Popular Survey Papers on Data Clustering       60         24.3.1 Free and Open-Source Software       616         24.3.1.1 General Clustering Software <th></th> <td></td> <td></td> <td></td> <td></td>													
23.2.3       Measure Normalization       577         23.2.3.1       Normalizing the Measures       578         23.2.3.2       The DCV Criterion       58         23.2.3.3       The Effect of Normalization       58         23.2.4.4       Measure Properties       58         23.2.4.1       The Consistency Between Measures       58         23.2.4.2       Properties of Measures       58         23.2.4.3       Discussions       58         23.3.1       An Overview of Internal Clustering Validation Measures       58         23.3.1       An Overview of Internal Clustering Validation Measures       58         23.3.1       The Impact of Monotonicity       59         23.3.2.1       The Impact of Noise       59         23.3.2.2       The Impact of Noise       59         23.3.2.3       The Impact of Subclusters       59         23.3.2.4       The Impact of Skewed Distributions       59         23.3.2.5       The Impact of Skewed Distributions       59         23.3.2.6       The Impact of Arbitrary Shapes       59         23.3.2       Summary       60         24.2       Educational and Software Resources for Data Clustering       60         24.2.1       Books on Data													
23.2.3.1       Normalizing the Measures       576         23.2.3.2       The DCV Criterion       58         23.2.3.3       The Effect of Normalization       58         23.2.4.4       Measure Properties       58         23.2.4.1       The Consistency Between Measures       58         23.2.4.2       Properties of Measures       58         23.2.4.3       Discussions       58         23.3       Internal Clustering Validation Measures       58         23.3.1       An Overview of Internal Clustering Validation Measures       58         23.3.1       An Overview of Internal Clustering Validation Measures       58         23.3.1       The Impact of Monotonicity       59         23.3.2.2       The Impact of Noise       59         23.3.2.2       The Impact of Density       59         23.3.2.3       The Impact of Subclusters       59         23.3.2.4       The Impact of Skewed Distributions       59         23.3.2.5       The Impact of Arbitrary Shapes       59         23.3.2       Summary       60         24       Educational and Software Resources for Data Clustering       60         24.2.1       Books on Data Clustering       60         24.2.2       Popular Sur			23.2.3		1 &								
23.2.3.2       The DCV Criterion       58:         23.2.3.3       The Effect of Normalization       58:         23.2.4.4       Measure Properties       58:         23.2.4.1       The Consistency Between Measures       58:         23.2.4.2       Properties of Measures       58:         23.2.4.3       Discussions       58:         23.3.1       An Overview of Internal Clustering Validation Measures       58:         23.3.1       An Overview of Internal Clustering Validation Measures       59:         23.3.2.1       The Impact of Monotonicity       59:         23.3.2.2       The Impact of Noise       59:         23.3.2.3       The Impact of Subclusters       59:         23.3.2.4       The Impact of Skewed Distributions       59:         23.3.2.5       The Impact of Skewed Distributions       59:         23.3.3.6       The Impact of Arbitrary Shapes       59:         23.3.3       Properties of Measures       60:         23.4       Summary       60:         24.2       Educational and Software Resources for Data Clustering       60:         24.2.1       Introduction       60:         24.2.2       Popular Survey Papers on Data Clustering       60:         24.2.2													
23.2.3.3 The Effect of Normalization       583         23.2.4 Measure Properties       584         23.2.4.1 The Consistency Between Measures       584         23.2.4.2 Properties of Measures       586         23.2.4.3 Discussions       586         23.3 Internal Clustering Validation Measures       588         23.3.1 An Overview of Internal Clustering Validation Measures       589         23.3.2 Understanding of Internal Clustering Validation Measures       592         23.3.2.1 The Impact of Monotonicity       592         23.3.2.2 The Impact of Density       592         23.3.2.3 The Impact of Density       594         23.3.2.4 The Impact of Subclusters       592         23.3.2.5 The Impact of Skewed Distributions       596         23.3.3 Properties of Measures       606         23.4 Summary       607         24 Educational and Software Resources for Data Clustering       607         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       608         24.3.1 Free and Open-Source Software       616         24.3.1.1 General Clustering Software       616													
23.2.4       Measure Properties       584         23.2.4.1       The Consistency Between Measures       584         23.2.4.2       Properties of Measures       586         23.2.4.3       Discussions       586         23.3       Internal Clustering Validation Measures       582         23.3.1       An Overview of Internal Clustering Validation Measures       582         23.3.2       Understanding of Internal Clustering Validation Measures       592         23.3.2.1       The Impact of Monotonicity       592         23.3.2.2       The Impact of Noise       592         23.3.2.3       The Impact of Density       594         23.3.2.4       The Impact of Subclusters       592         23.3.2.5       The Impact of Skewed Distributions       596         23.3.3       Properties of Measures       606         23.4       Summary       607         24       Educational and Software Resources for Data Clustering       607         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.2.3       Software for Data Clustering       608         24.3.1       Free and Open-Source Software       610         24													
23.2.4.1       The Consistency Between Measures       584         23.2.4.2       Properties of Measures       586         23.2.4.3       Discussions       585         23.3       Internal Clustering Validation Measures       585         23.3.1       An Overview of Internal Clustering Validation Measures       585         23.3.2       Understanding of Internal Clustering Validation Measures       592         23.3.2.1       The Impact of Monotonicity       592         23.3.2.2       The Impact of Noise       592         23.3.2.3       The Impact of Density       594         23.3.2.4       The Impact of Subclusters       592         23.3.2.5       The Impact of Skewed Distributions       596         23.3.2.6       The Impact of Arbitrary Shapes       598         23.3.2.6       The Impact of Arbitrary Shapes       598         23.3.2.8       Properties of Measures       600         24.4       Summary       607         24.2       Educational and Software Resources for Data Clustering       607         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.3.1       Free and Open-Source Software       610			23 2 4										
23.2.4.2       Properties of Measures       586         23.2.4.3       Discussions       589         23.3       Internal Clustering Validation Measures       589         23.3.1       An Overview of Internal Clustering Validation Measures       592         23.3.2.2       Understanding of Internal Clustering Validation Measures       592         23.3.2.1       The Impact of Monotonicity       592         23.3.2.2       The Impact of Noise       592         23.3.2.3       The Impact of Density       594         23.3.2.4       The Impact of Subclusters       592         23.3.2.5       The Impact of Skewed Distributions       596         23.3.2.6       The Impact of Arbitrary Shapes       598         23.3.3       Properties of Measures       600         23.4       Summary       601         24       Educational and Software Resources for Data Clustering       602         24.1       Introduction       603         24.2.1       Books on Data Clustering       603         24.2.2       Popular Survey Papers on Data Clustering       608         24.3.1       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610			23.2.1										
23.2.4.3 Discussions       589         23.3 Internal Clustering Validation Measures       589         23.3.1 An Overview of Internal Clustering Validation Measures       589         23.3.2 Understanding of Internal Clustering Validation Measures       592         23.3.2.1 The Impact of Monotonicity       592         23.3.2.2 The Impact of Noise       593         23.3.2.3 The Impact of Density       594         23.3.2.4 The Impact of Subclusters       596         23.3.2.5 The Impact of Skewed Distributions       596         23.3.3 Properties of Measures       600         23.4 Summary       600         24 Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       608         24.1 Introduction       607         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       608         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610													
23.3       Internal Clustering Validation Measures       589         23.3.1       An Overview of Internal Clustering Validation Measures       589         23.3.2       Understanding of Internal Clustering Validation Measures       592         23.3.2.1       The Impact of Monotonicity       592         23.3.2.2       The Impact of Noise       593         23.3.2.3       The Impact of Density       594         23.3.2.4       The Impact of Subclusters       596         23.3.2.5       The Impact of Skewed Distributions       596         23.3.3       Properties of Measures       600         23.4       Summary       600         24       Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       607         24.1       Introduction       607         24.2       Educational Resources       608         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.3       Software for Data Clustering       610         24.3.1       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610													
23.3.1       An Overview of Internal Clustering Validation Measures       589         23.3.2       Understanding of Internal Clustering Validation Measures       592         23.3.2.1       The Impact of Monotonicity       592         23.3.2.2       The Impact of Noise       593         23.3.2.3       The Impact of Density       594         23.3.2.4       The Impact of Subclusters       594         23.3.2.5       The Impact of Skewed Distributions       596         23.3.3       Properties of Measures       600         23.4       Summary       607         24 Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       608         24.1       Introduction       608         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.3       Software for Data Clustering       610         24.3       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610		23.3	Internal										
23.3.2       Understanding of Internal Clustering Validation Measures       592         23.3.2.1       The Impact of Monotonicity       592         23.3.2.2       The Impact of Noise       593         23.3.2.3       The Impact of Density       594         23.3.2.4       The Impact of Subclusters       596         23.3.2.5       The Impact of Skewed Distributions       596         23.3.2.6       The Impact of Arbitrary Shapes       598         23.4       Summary       606         24.4       Summary       607         24 Educational and Software Resources for Data Clustering       607         24.1       Introduction       607         24.2.1       Books on Data Clustering       608         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.3       Software for Data Clustering       608         24.3.1       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610		23.3											
23.3.2.1 The Impact of Monotonicity       592         23.3.2.2 The Impact of Noise       593         23.3.2.3 The Impact of Density       594         23.3.2.4 The Impact of Subclusters       595         23.3.2.5 The Impact of Skewed Distributions       596         23.3.2.6 The Impact of Arbitrary Shapes       598         23.3.3 Properties of Measures       600         23.4 Summary       601         24 Educational and Software Resources for Data Clustering       602         Charu C. Aggarwal and Chandan K. Reddy       603         24.1 Introduction       603         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       608         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610													
23.3.2.2       The Impact of Noise       593         23.3.2.3       The Impact of Density       594         23.3.2.4       The Impact of Subclusters       595         23.3.2.5       The Impact of Skewed Distributions       596         23.3.2.6       The Impact of Arbitrary Shapes       598         23.3.3       Properties of Measures       600         23.4       Summary       601         24       Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       607         24.1       Introduction       607         24.2       Educational Resources       608         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.3       Software for Data Clustering       608         24.3.1       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610			23.3.2										
23.3.2.3 The Impact of Density       594         23.3.2.4 The Impact of Subclusters       595         23.3.2.5 The Impact of Skewed Distributions       596         23.3.2.6 The Impact of Arbitrary Shapes       598         23.3.3 Properties of Measures       600         23.4 Summary       607         24 Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       607         24.1 Introduction       607         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       608         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610													
23.3.2.4 The Impact of Subclusters       596         23.3.2.5 The Impact of Skewed Distributions       596         23.3.2.6 The Impact of Arbitrary Shapes       598         23.3.3 Properties of Measures       600         23.4 Summary       607         24 Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       607         24.1 Introduction       608         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       610         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610													
23.3.2.5       The Impact of Skewed Distributions       596         23.3.2.6       The Impact of Arbitrary Shapes       598         23.3.3       Properties of Measures       600         23.4       Summary       607         24 Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       607         24.1       Introduction       608         24.2       Educational Resources       608         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.3       Software for Data Clustering       608         24.3.1       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610					1								
23.3.2.6 The Impact of Arbitrary Shapes       598         23.3.3 Properties of Measures       600         23.4 Summary       602         24 Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       607         24.1 Introduction       608         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       610         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610					1								
23.3.3 Properties of Measures       600         23.4 Summary       607         24 Educational and Software Resources for Data Clustering       607         Charu C. Aggarwal and Chandan K. Reddy       607         24.1 Introduction       608         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       610         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610													
23.4 Summary       60.2         24 Educational and Software Resources for Data Clustering       60.2         Charu C. Aggarwal and Chandan K. Reddy       60.2         24.1 Introduction       60.2         24.2 Educational Resources       60.8         24.2.1 Books on Data Clustering       60.8         24.2.2 Popular Survey Papers on Data Clustering       60.8         24.3 Software for Data Clustering       61.0         24.3.1 Free and Open-Source Software       61.0         24.3.1.1 General Clustering Software       61.0			2222										
24 Educational and Software Resources for Data Clustering       60%         Charu C. Aggarwal and Chandan K. Reddy       60%         24.1 Introduction       60%         24.2 Educational Resources       60%         24.2.1 Books on Data Clustering       60%         24.2.2 Popular Survey Papers on Data Clustering       60%         24.3 Software for Data Clustering       61%         24.3.1 Free and Open-Source Software       61%         24.3.1.1 General Clustering Software       61%		22.4		-									
Charu C. Aggarwal and Chandan K. Reddy       607         24.1 Introduction       608         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       610         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610		23.4	Summai	r <b>y</b>									
24.1 Introduction       607         24.2 Educational Resources       608         24.2.1 Books on Data Clustering       608         24.2.2 Popular Survey Papers on Data Clustering       608         24.3 Software for Data Clustering       610         24.3.1 Free and Open-Source Software       610         24.3.1.1 General Clustering Software       610	24	Educa	ational a	nd Softwa	re Resources for Data Clustering 60								
24.2       Educational Resources       608         24.2.1       Books on Data Clustering       608         24.2.2       Popular Survey Papers on Data Clustering       608         24.3       Software for Data Clustering       610         24.3.1       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610		Chari	C. Agga	rwal and C	Chandan K. Reddy								
24.2.1 Books on Data Clustering60824.2.2 Popular Survey Papers on Data Clustering60824.3 Software for Data Clustering61024.3.1 Free and Open-Source Software61024.3.1.1 General Clustering Software610		24.1	Introduc	ction									
24.2.1 Books on Data Clustering60824.2.2 Popular Survey Papers on Data Clustering60824.3 Software for Data Clustering61024.3.1 Free and Open-Source Software61024.3.1.1 General Clustering Software610		24.2	Education	onal Resou	rces								
24.2.2 Popular Survey Papers on Data Clustering													
24.3       Software for Data Clustering       610         24.3.1       Free and Open-Source Software       610         24.3.1.1       General Clustering Software       610			24.2.2		· · · · · · · · · · · · · · · · · · ·								
24.3.1 Free and Open-Source Software		24.3		-	<i>5</i> 1								
24.3.1.1 General Clustering Software 610					-								
· · · · · · · · · · · · · · · · · · ·													

xx Contents

Index		617
24.4	Summary	612
	24.3.3 Data Benchmarks for Software and Research	611
	24.3.2 Commercial Packages	611