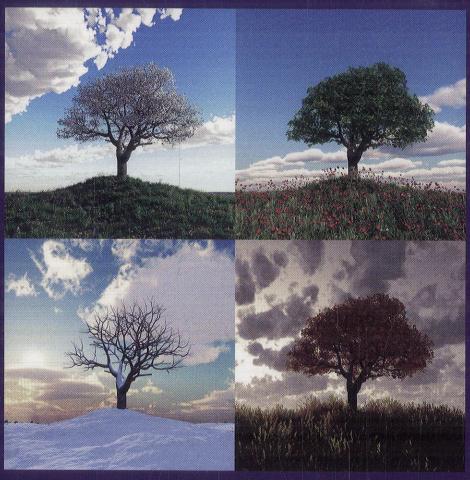
Chapman & Hall/CRC
Data Mining and Knowledge Discovery Series

## Temporal Data Mining



Theophano Mitsa



## **Table of Contents**

## Preface, xix

CHAPTE	r 1 • Te	emporal Databases and Mediators	1
1.1	TIME	in databases	1
	1.1.1	Database Concepts	2
	1.1.2	Temporal Databases	3
	1.1.3	Time Representation in SQL	4
	1.1.4	Time in Data Warehouses	5
	1.1.5	Temporal Constraints and Temporal Relations	5
	1.1.6	Requirements for a Temporal Knowledge- Based Management System	6
	1.1.7	Using XML for Temporal Data	7
	1.1.8	Temporal Entity Relationship Models	8
1.2	DATA	BASE MEDIATORS	9
	1.2.1	Temporal Relation Discovery	10
	1.2.2	Semantic Queries on Temporal Data	12
1.3	ADDI	TIONAL BIBLIOGRAPHY	15
	1.3.1	Additional Bibliography on Temporal Primitives	15
	1.3.2	Additional Bibliography on Temporal Constraints and Logic	15

	1.3.3		nal Bibliography on Temporal Languages neworks	16
REF	ERENCE	ES		1 <i>7</i>
Силоте	p 2 ∎ Ta	mnoral	Data Similarity Computation,	
CHAPTE		•	ation, and Summarization	21
2.1		·	ATA TYPES AND PREPROCESSING	22
	2.1.1	Tempora	al Data Types	22
	2.1.2	_	al Data Preprocessing	22
		2.1.2.1	Data Cleaning	22
		2.1.2.2	Data Normalization	25
2.2	TIME	SERIES SI	MILARITY MEASURES	26
	2.2.1	Distance	e-Based Similarity	27
		2.2.1.1	Euclidean Distance	27
		2.2.1.2	Absolute Difference	28
		2.2.1.3	Maximum Distance Metric	28
	2.2.2	Dynami	c Time Warping	28
	2.2.3	The Lon	gest Common Subsequence	31
	2.2.4	Other T	ime Series Similarity Metrics	31
2.3	TIME	SERIES R	epresentation	33
	2.3.1	Nonada	ptive Representation Methods	33
		2.3.1.1	Discrete Fourier Transform	34
		2.3.1.2	Discrete Wavelet Transform	34
		2.3.1.3	Piecewise Aggregate Composition	37
	2.3.2	Data-Ad	laptive Representation Methods	38
		2.3.2.1	Singular Value Decomposition of Time Sequences	38
		2.3.2.2	Shape Definition Language and CAPSUL	39
		2.3.2.3	Landmark-Based Representation	40
		2.3.2.4	Symbolic Aggregate Approximation (SAX) and iSAX	42
		2.3.2.5	Adaptive Piecewise Constant Approximation (APCA)	43

		2.3.2.6	Piecewise Linear Representation (PLA)	43
	2.3.3	Model-I	Based Representation Methods	44
		2.3.3.1	Markov Models for Representation and	
			Analysis of Time Series	44
	2.3.4	Data Di	ctated Representation Methods	45
		2.3.4.1	Clipping	45
	2.3.5	_	rison of Representation Schemes and	
			e Measures	45
	2.3.6		r Time Series Data Mining Benchmarks	46
2.4	TIME:	SERIES S	ummarization methods	46
	2.4.1	Statistic	s-Based Summarization	47
		2.4.1.1	Mean	47
		2.4.1.2	Median	47
		2.4.1.3	Mode	<b>4</b> 7
		2.4.1.4	Variance	47
	2.4.2	Fractal 1	Dimension-Based Summarization	48
	2.4.3	Run-Le	ngth–Based Signature	48
		2.4.3.1	Short Run-Length Emphasis	49
		2.4.3.2	Long Run-Length Emphasis	49
	2.4.4	Histogr	am-Based Signature and Statistical	
		Measur	es	50
	2.4.5	Local T	rend-Based Summarization	51
2.5	TEMP	ORAL E	vent representation	52
	2.5.1	Event R	epresentation Using Markov Models	52
	2.5.2	A Form	alism for Temporal Objects and	
		Repetit		53
2.6			COMPUTATION OF SEMANTIC	<b>-</b> 4
		PORAL C	·	54
2.7			NOWLEDGE REPRESENTATION ED REASONING SYSTEMS	55
<b>ງ</b> 0			BIBLIOGRAPHY	56
2.8				
	2.8.1		ity Measures	56
	2.8.2	Dimens	sionality Reduction	57

	2.8.3	Represer	ntation and Summarization Techniques	58
	2.8.4	Similarit	y and Query of Data Streams	59
REFE	RENCE	ES		59
Снарте	R 3 ∎Te	mnoral	Data Classification and Clustering	67
3.1			ON TECHNIQUES	68
	3.1.1		e-Based Classifiers	68
	01212	3.1.1.1	K–Nearest Neighbors	69
			Exemplar-Based Nearest Neighbor	72
	3.1.2	Bayes C	-	72
	3.1.3	Decision		78
	3.1.4		Vector Machines in Classification	81
	3.1.5		Networks in Classification	82
	3.1.6	Classific	ation Issues	83
		3.1.6.1	Classification Error Types	83
		3.1.6.2	Classifier Success Measures	84
		3.1.6.3	Generation of the Testing and	
			Training Sets	85
		3.1.6.4	Comparison of Classification	0.5
			Approaches	85
			Feature Processing	85
			Feature Selection	86
3.2	CLUS	TERING		86
	3.2.1	Clusteri	ng via Partitioning	87
		3.2.1.1	K-Means Clustering	87
		3.2.1.2	K-Medoids Clustering	88
	3.2.2	Hierarc	hical Clustering	90
		3.2.2.1	The COBWEB Algorithm	92
		3.2.2.2	The BIRCH Algorithm	92
		3.2.2.3	The CURE Algorithm	93
	3.2.3	Density	-Based Clustering	93

			3.2.3.1 The DBSCAN Algorithm	94
		3.2.4	Fuzzy C-Means Clustering	95
		3.2.5	Clustering via the EM Algorithm	96
	3.3		IER ANALYSIS AND MEASURES OF FER VALIDITY	96
	3.4		SERIES CLASSÍFICATION AND FERING TECHNIQUES	99
		3.4.1	1-NN Time Series Classification	99
		3.4.2	Improvement to the <i>1NN-DTW</i> Algorithm Using Numerosity Reduction	100
		3.4.3	Semi-Supervised Time Series Classification	100
		3.4.4	Time Series Classification Using Learned Constraints	101
		3.4.5	Entropy-Based Time Series Classification	102
		3.4.6	Incremental Iterative Clustering of Time Series	103
		3.4.7	Motion Time Series Clustering Using Hidden Markov Models (HMMs)	103
		3.4.8	Distance Measures for Effective Clustering of ARIMA Time Series	104
		3.4.9	Clustering of Time Series Subsequences	104
		3.4.10	Clustering of Time Series Data Streams	105
		3.4.11	Model-Based Time Series Clustering	107
		3.4.12	Time Series Clustering Using Global Characteristics	107
	3.5	ADDI	tional bibliography	108
		3.5.1	General Classification and Clustering	108
		3.5.2	Time Series/Sequence Classification	108
		3.5.3	Time Series Clustering	110
	REFE	RENCE	S .	112
C	HAPTE	R 4 ■ Pr	rediction	121
	4.1	FORE	casting model and error measures	122
	4.2	EV/ENI	T PREDICTION	124

		4.2.1	Simple Linear Regression	124
		4.2.2	Linear Multiple Regression	126
		4.2.3	Other Regression Issues	129
		4.2.4	Learning to Predict Rare Events in	
			Event Sequences	131
	4.3	TIME S	series forecasting	133
		4.3.1	Moving Averages	133
		4.3.2	Exponential Smoothing	134
		4.3.3	Time Series Forecasting via Regression	137
		4.3.4	Forecasting Seasonal Data via Regression	137
		4.3.5	Random Walk	138
		4.3.6	Autocorrelation	140
		4.3.7	Autoregression	141
		4.3.8	ARMA Models	142
	4.4		NCED TIME SERIES FORECASTING NIQUES	143
		4.4.1	Neural Networks and Genetic Algorithms in Time Series Forecasting	143
		4.4.2	Application of Clustering in Time Series Forecasting	145
		4.4.3	Characterization and Prediction of Complex Time Series Events Using Time-Delayed	
			Embedding	146
	4.5	ADDI	TIONAL BIBLIOGRAPHY	147
	REFE	RENCE	SS .	149
C	HAPTE	к 5 <b>•</b> Те	emporal Pattern Discovery	153
	5.1	SEQU	ENCE MINING	154
		5.1.1	Apriori Algorithm and Its Extension to Sequence Mining	154
		5,1.2	The GSP Algorithm	157
			5.1.2.1 Candidate Generation	158
		5.1.3	The SPADE Algorithm	159

	5.1.4	The Pref	SixSpan and CloSpan Algorithms	160
	5.1.5	The SPA	M and I-SPAM Algorithms	161
	5.1.6	The Free	quent Pattern Tree (FP-Tree) Algorithm	162
	5.1.7	The Dat	te Algorithm	163
	5.1.8	Increme	ental Mining of Databases for	
		Frequen	nt Sequence Discovery	164
5.2	FREQ	uent ef	PISODE DISCOVERY	165
5.3	TEMP	ORAL AS	SSOCIATION RULE DISCOVERY	166
	5.3.1	-	al Association Rule Discovery Senetic Programming and Specialized	
		Hardwa		167
	5.3.2	Meta-M	ining of Temporal Data Sets	168
	5.3.3	Other T	echniques for the Discovery of	
		Tempor	al Association Rules	168
5.4	PATTI	ERN DISC	COVERY IN TIME SERIES	169
	5.4.1	Motif D	iscovery	169
		5.4.1.1	General Concepts	169
		5.4.1.2	, ,	
			Time Series Motifs	170
		5.4.1.3	Discovering Motifs in Multivariate	
		~	Time Series	171
		5.4.1.4	Activity Discovery	171
	5.4.2		ly Discovery	172
			General Concepts	172
		5.4.2.2		172
			VizTree	173
		5.4.2.4	1 ,	154
	<b>5</b> 4 0	4 1 10.1	Using Support Vector Machines	174
	5.4.3	Addition Discove	nal Work in Motif and Anomaly	175
	5.4.4		•	173
	J.4,4	Time Se	l Partial Periodicity Detection in	175
	5.4.5		ex Temporal Pattern Identification	178
	- /			_, _

	5.4.6	Retrieval of Relative Temporal Patterns Using Signatures	179
	5.4.7	Hidden Markov Models for Temporal Pattern Discovery	179
5.5	FIND	ING PATTERNS IN STREAMING TIME SERIES	180
	5.5.1	SPIRIT, BRAID, Statstream, and Other Stream	
		Pattern Discovery Algorithms	180
	5.5.2	Multiple Regression of Streaming Data	181
	5,5.3	A Warping Distance for Streaming Time Series	182
	5.5.4	Burst Detection in Data Streams	182
	5,5.5	The MUSCLES and Selective MUSCLES	
		Algorithms	183
	5.5.6	The AWSOM Algorithm	184
5.6	MINII	ng temporal patterns in multimedia	185
5.7	ADDI	TIONAL BIBLIOGRAPHY	187
	5.7.1	Sequential Pattern Mining	187
	5.7.2	Time Series Pattern Discovery	188
REF	ERENCE	ES	192
Снарте		emporal Data Mining in Medicine and	201
		ioinformatics	201
6.1		ORAL PATTERN DISCOVERY, CLASSIFICATION CLUSTERING	
			201
	6.1.1	Temporal Mining in Clinical Databases	201
	6.1.2	Various Physiological Signal Temporal Mining	204
	6.1.3	ECG Analysis	208
	6.1.4	Analysis and Classification of EEG Time Series	209
		Analysis and Clustering of fMRI Data	210
	6.1.6	Fuzzy Temporal Data Mining and Reasoning	211
	6.1.7	Analysis of Gene Expression Profile Data	212
		6.1.7.1 Pattern Discovery in Gene Sequences	213
		6.1.7.2 Clustering of Static Gene Expression Data	216
		6.1.7.3 Clustering of Gene Expression Time Series	217

	·	6.1.7.4	Additional Temporal Data Mining-Related Work for Genomic Data	223
	6.1.8	Tempora Reasonia	al Patterns Extracted via Case-Based	225
	6.1.9	Processi	ed Environments for the Extraction, ng, and Visualization of Temporal Information	226
6.2	TEMPO	ORAL DA	ATABASES/MEDIATORS	228
	6.2.1	Medical	Temporal Reasoning	228
	6.2.2	Knowled Domain	lge-Based Temporal Abstraction in Clinical s	229
	6.2.3	-	al Database Mediators and Architectures ract Temporal Queries	231
	6.2.4	_	ality of Narrative Clinical Information and Discharge Documents	234
	6.2.5	-	ality Incorporation and Temporal Data in Electronic Health Records	235
	6.2.6	The Bio)	ournal Monitor	237
6.3	TEMP	ORALITY	IN CLINICAL WORKFLOWS	237
	6.3.1	Clinical	Workflow Management	237
	6.3.2	•	ng Clinical Workflows by al Similarity	239
	6.3.3	Surgical	Workflow Temporal Modeling	240
6.4	ADDI	TIONAL	BIBLIOGRAPHY	240
REFE	RENCE	ES		243
Снартеі		-	Data Mining and Forecasting in and Industrial Applications	257
7.1	ENH/		ATA MINING APPLICATIONS IN NT OF BUSINESS AND CUSTOMER	258
	7.1.1		ased Marketing and Business Strategy	258
	7.1.2		s Strategy Implementation via Temporal	260

	7.1.3	Temporality of Business Decision Making and	
		Integration of Temporal Research in Business	261
	7.1.4	Intertemporal Economies of Scope	263
	7.1.5	Time-Based Competition	264
	7.1.6	A Model for Customer Lifetime Value	265
7.2	BUSIN	NESS PRÓCESS APPLICATIONS	267
	7.2.1	Business Process Workflow Management	267
	7.2.2	Temporal Data Mining to Measure Operations Performance	267
	7.2.3	Temporality in the Supply Chain Management	268
	7.2.4	Temporal Data Mining for the Optimization of the Value Chain Management	269
	7.2.5	Resource Demand Forecasting Using Sequence Clustering	270
	7.2.6	A Temporal Model to Measure the Performance of an IT Project	271
	7.2.7	Real-Time Business Analytics	272
	7.2.8	Choreographing Web Services for Real-Time Data Mining	272
	7.2.9	Temporal Business Rules to Synthesize Composition of Web Services	273
7.3	MISC	ellaneous industrial applications	273
	7.3.1	Temporal Management of RFID Data	273
	7.3.2	Time Correlations of Data Streams and Their Effects on Business Impact Analysis	275
	7.3.3	Temporal Data Mining in a Large Utility Company	276
	7.3.4	The Partition Decoupling Method for Time-Dependent Complex Data	277
7.4	FINA	ncial data forecasting	277
	7.4.1	A Model for Multirelational Data Mining on Demand Forecasting	277
	7.4.2	Simultaneous Prediction of Multiple Financial Time Series Using Supervised Learning and	
		Chaos Theory	278

	7.4.3	Financial Forecasting through Evolutionary Algorithms and Neural Networks	279
	7.4.4	Independent Component Analysis for Financial Time Series	282
	7.4.5	Subsequence Matching of Financial Streams	282
	7.4.6	Detection of Outliers in Financial Data	283
	7.4.7	Stock Portfolio Diversification Using the Fractal Dimension	284
7.5	ADDI	TIONAL BIBLIOGRAPHY	284
REFE	ERENCE	ES .	286
Снарте	r 8 <b>•</b> W	/eb Usage Mining	293
8.1	GENE	ral concepts	293
	8.1.1	Preprocessing	294
	8.1.2	Pattern Discovery and Analysis in Web Usage	295
	8.1.3	Business Applications of Web Usage Mining	296
8.2	WEB	USAGE MINING ALGORITHMS	297
	8.2.1	Mining Web Usage Patterns	297
	8.2.2	Automatic Personalization of a Web Site	298
	8.2.3	Measuring and Improving the Success of Web Sites	300
	8.2.4	Identification of Online Communities	303
	8.2.5	Web Usage Mining in Real Time	304
	8.2.6	Mining Evolving User Profiles	304
	8.2.7	Identifying Similarities, Periodicities, and Bursts in Online Search Queries	305
	8.2.8	Event Detection from Web-Click-Through Data	307
8.3	ADDI	ITIONAL BIBLIOGRAPHY	308
	8.3.1	Pattern Discovery	308
	8.3.2	Web Usage Mining for Business Applications	309
REF	erenci	ES	310
Снарте	:R 9 • S	patiotemporal Data Mining	315
9.1		ERAL CONCEPTS	315

9.2	FINDING PERIODIC PATTERNS IN	
	SPATIOTEMPORAL DATA	316
9.3	MINING ASSOCIATION RULES IN	
	SPATIOTEMPORAL DATA	317
9.4	APPLICATIONS OF SPATIOTEMPORAL	
	DATA MINING IN GEOGRAPHY	318
9.5	SPATIOTEMPORAL DATA MINING OF	220
	TRAFFIC DATA	320
9.6	SPATIOTEMPORAL DATA REDUCTION	321
9.7	SPATIOTEMPORAL DATA QUERIES	322
9.8	INDEXING SPATIOTEMPORAL DATA WAREHOUSES	322
9.9	SEMANTIC REPRESENTATION OF	
	SPATIOTEMPORAL DATA	323
	HISTORICAL SPATIOTEMPORAL AGGREGATION	324
9.11	SPATIOTEMPORAL RULE MINING FOR	205
	LOCATION-BASED AWARE SYSTEMS	325
	TRAJECTORY DATA MINING	326
9.13	THE FLOWMINER ALGORITHM	327
9.14	THE TOPOLOGYMINER ALGORITHM	329
9.15	APPLICATIONS OF TEMPORAL DATA MINING	
	in the environmental sciences	329
9.16	ADDITIONAL BIBLIOGRAPHY	332
	9.16.1 Modeling of Spatiotemporal Data and Query	
	Languages	333
	9.16.2 Moving Object Databases	333
REFE	RENCES	334
APP	endix A	339
APP	endix B	345
IND	EX	353