

Contents

Part I Setting the Scene

1 Introduction	3
1.1 About Mobility Data.....	3
1.1.1 Global Positioning System (GPS).....	5
1.1.2 Format of GPS Data.....	6
1.1.3 Examples of Trajectory Datasets.....	8
1.2 What Can We Learn from Mobility Data.....	9
1.3 Location- and Mobility-Aware Applications.....	12
1.4 Adding Mobility in Spatial Database Systems.....	15
1.5 Summary.....	17
1.6 Exercises.....	17
1.7 Bibliographical Notes and Online Resources.....	17
References.....	19
2 Background on Spatial Data Management and Exploration	21
2.1 Spatial Data Modeling.....	21
2.2 Spatial Database Management.....	25
2.2.1 Abstract Data Types.....	25
2.2.2 Indexing and Query Processing Issues.....	26
2.3 Spatial Data Warehousing.....	32
2.4 Spatial Data Mining.....	34
2.4.1 Cluster Analysis.....	35
2.4.2 Co-Location Pattern Mining.....	39
2.5 Data Privacy Aspects.....	39
2.6 Summary.....	42
2.7 Exercises.....	43
2.8 Bibliographical Notes.....	44
References.....	46

Part II Mobility Data Management

3	Modeling and Acquiring Mobility Data	51
3.1	Modeling Mobility Data	51
3.2	Acquiring Trajectories from Raw Data.....	54
3.2.1	GPS Data Cleansing.....	56
3.2.2	Trajectory Identification.....	57
3.3	Trajectory Reconstruction and Simplification	59
3.3.1	Trajectory Reconstruction via Map-Matching.....	59
3.3.2	Trajectory Simplification via Data Compression.....	63
3.4	Trajectory Data Generators	64
3.4.1	Generating Trajectories in Free Space	65
3.4.2	Generating Network-Constrained Trajectories	65
3.5	Summary	69
3.6	Exercises	70
3.7	Bibliographical Notes	70
	References.....	72
4	Mobility Database Management	75
4.1	Location- and Mobile-Aware Querying	75
4.1.1	Location-Oriented Queries.....	77
4.1.2	Trajectory-Oriented Queries	78
4.1.3	Querying Under Uncertainty.....	79
4.2	Indexing Techniques for Mobility Data	81
4.2.1	Indexing Trajectories in Free Space.....	82
4.2.2	Indexing Network-Constrained Trajectories.....	85
4.3	Query Processing Techniques	87
4.3.1	Processing Location-Oriented Queries	87
4.3.2	Processing Trajectory-Oriented Queries.....	89
4.4	Benchmarks.....	91
4.5	Summary	93
4.6	Exercises	94
4.7	Bibliographical Notes	95
	References.....	97
5	Moving Object Database Engines	101
5.1	From Spatial Database Systems to MOD Engines	102
5.1.1	SECONDO.....	103
5.1.2	Hermes	104
5.2	A Data Type Model for Trajectory Databases	105
5.2.1	Preliminaries of Trajectory Data Types	105
5.2.2	Trajectory-Oriented Data Types.....	106
5.3	Extending the Trajectory Data Type Model with Object Methods and Operators	109
5.3.1	Predicates and Projection Methods.....	109
5.3.2	Numeric Operations	111

5.3.3	Distance Functions.....	111
5.3.4	Query Operators.....	112
5.4	On Mobility Data Provenance.....	113
5.5	Summary.....	114
5.6	Exercises.....	115
5.7	Bibliographical Notes.....	116
	References.....	117

Part III Mobility Data Exploration

6	Preparing for Mobility Data Exploration.....	121
6.1	Mobility Data Warehousing.....	121
6.1.1	Modeling Trajectory Data Cubes.....	122
6.1.2	Performing ETL Process.....	123
6.2	OLAP Analysis in Trajectory Data Cubes.....	125
6.2.1	Addressing the Distinct Count Problem.....	126
6.2.2	Indexing Summary Information for Efficient OLAP.....	126
6.3	Calculating Similarity Between Trajectories.....	128
6.3.1	Functions Computed over the Sampled Points.....	128
6.3.2	Computing the Similarity Between Entire Trajectories or Sub-trajectories.....	134
6.4	Summary.....	137
6.5	Exercises.....	138
6.6	Bibliographical Notes.....	138
	References.....	140
7	Mobility Data Mining and Knowledge Discovery.....	143
7.1	Clustering in Mobility Data.....	143
7.1.1	Extending Off-the-Shelf Algorithms for Trajectory Clustering.....	143
7.1.2	Sub-trajectory Clustering Methods.....	147
7.1.3	Finding Representatives in a Trajectory Dataset.....	150
7.2	Moving Clusters for Capturing Collective Mobility Behavior.....	152
7.2.1	Flocks and Variants.....	152
7.2.2	Moving Clusters.....	154
7.2.3	Improvements over Flocks and Moving Clusters.....	155
7.3	Sequence Pattern Mining in Mobility Data.....	157
7.4	Prediction and Classification in Mobility Data.....	159
7.4.1	Future Location Prediction.....	159
7.4.2	Classification and Outlier Detection.....	160
7.5	Summary.....	163
7.6	Exercises.....	164
7.7	Bibliographical Notes.....	165
	References.....	166

8 Privacy-Aware Mobility Data Exploration	169
8.1 Privacy in Location-Based Services.....	170
8.1.1 Privacy in Snapshot LBS.....	171
8.1.2 Privacy in Continuous LBS.....	173
8.2 Privacy Preserving Mobility Data Publishing.....	175
8.2.1 Never-Walk-Alone (NWA).....	176
8.2.2 Always-Walk-with-Others (AWO).....	177
8.3 Privacy Preserving Mobility Data Querying.....	178
8.4 Summary.....	181
8.5 Exercises.....	182
8.6 Bibliographical Notes.....	183
References.....	184

Part IV Advanced Topics

9 Semantic Aspects on Mobility Data	189
9.1 From Raw to Semantic Trajectories.....	190
9.2 The Semantic Enrichment Process of Raw Trajectories.....	191
9.2.1 Trajectory Segmentation and Stop Discovery.....	192
9.2.2 Semantic Annotation of Episodes.....	194
9.3 Semantic Trajectory Data Management.....	196
9.3.1 A Datatype System for Semantic Trajectories.....	197
9.3.2 Indexing Semantic-Aware Trajectory Databases.....	200
9.4 Semantic Trajectory Data Exploration.....	201
9.4.1 Semantic-Aware Trajectory Data Warehouses.....	201
9.4.2 Mining Semantic Trajectory Databases.....	203
9.5 Semantic Aspects of Privacy.....	204
9.5.1 LBS for Sensitive Semantic Locations.....	204
9.5.2 Privacy in Semantic Trajectory Databases.....	205
9.6 Summary.....	206
9.7 Exercises.....	206
9.8 Bibliographical Notes.....	207
References.....	208
10 The Case of Big Mobility Data	211
10.1 Introduction to Big Data.....	211
10.2 The MapReduce Programming Model.....	213
10.2.1 Hadoop.....	215
10.2.2 HadoopDB.....	217
10.3 Handling Big Spatial Data.....	218
10.3.1 MapReduce-Based Approaches.....	219
10.3.2 A Hybrid Spatial DBMS—MapReduce Approach.....	221

10.4	Handling Big Mobility Data	222
10.4.1	Offline Mobility Data Analytics	222
10.4.2	Hybrid Historical—Real-Time Approaches Using MapReduce.....	224
10.5	Summary	228
10.6	Exercises	229
10.7	Bibliographical Notes	230
	References.....	231

Part V Epilogue, Hands-on

11	Epilogue	235
11.1	Bibliographical Notes	236
	References.....	237
12	Hands-on with Hermes@Oracle MOD	239
12.1	Introduction: The Hermes@Oracle Data Type System	239
12.2	The ‘Attiki’ Dataset.....	241
12.3	Extracting Dataset Statistics	243
12.4	Querying the Raw GPS Part of the Dataset	245
12.4.1	Queries on Individual Trajectories.....	245
12.4.2	Index-Supported Queries	254
12.5	Querying the Semantically-Enriched Part of the Dataset.....	258
12.6	Trajectory Warehousing and OLAP in Hermes@Oracle.....	265
12.7	Progressive Explorative Analysis via Querying and Mining Operations	267
13	Hands-on with Hermes@Postgres MOD	279
13.1	Introduction: The Hermes@Postgres Data Type System.....	279
13.2	AIS Dataset Description	280
13.3	Loading the AIS Dataset into Hermes@Postgres	281
13.4	Querying the AIS Dataset	283
13.4.1	Timeslice, Range and Nearest-Neighbor Queries.....	283
13.4.2	Join Queries	288
13.4.3	Topological Queries	290
13.4.4	Cross-Tab Queries.....	294
13.5	Visualization Tips	297
	Authors’ Bios	299