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978-1-107-02171-6 - Mobility Data: Modeling, Management, and Understanding

Edited by Chiara Renso, Stefano Spaccapietra and Esteban Zimányi

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## Mobility Data

Mobility of people and goods is essential in the global economy. The ability to track the routes and patterns associated with this mobility offers unprecedented opportunities for developing new, smarter applications in different domains. Much of the current research is devoted to developing concepts, models, and tools to comprehend mobility data and make them manageable for these applications.

This book surveys the myriad facets of mobility data, from spatio-temporal data modeling, to data aggregation and warehousing, to data analysis, with a specific focus on monitoring people in motion (drivers, airplane passengers, crowds, and even animals in the wild). Written by a renowned group of worldwide experts, it presents a consistent framework that facilitates understanding of all these different facets, from basic definitions to state-of-the-art concepts and techniques, offering both researchers and professionals a thorough understanding of the applications and opportunities made possible by the development of mobility data.

Chiara Renso is a permanent researcher at the Institute of Information Science and Technologies at the Italian National Research Council, Italy. Her research interests are related to spatio-temporal data mining, reasoning, data mining query languages, semantic data mining, and trajectory data mining.

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# *Mobility Data*

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Modeling, Management, and Understanding

*Edited by*

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## PREFACE

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From the invention of the wheel to moon-landing rockets, technological progress over thousands of years has produced increasingly powerful and efficient transportation means, thus making moving easier and easier. Most recent progress in telecommunications has added new facets to mobility. We have now the ability to automatically keep track of our travel routes and even document them with information such as photos about the places we have been. This prompted the surge of small to huge databases holding mobility data, that is, the data about where and when we have been all over the world as well as during our daily trips to reach our workplace. Complementarily, more and more applications in a great variety of domains have been or are being developed to make intelligent use of mobility data.

While most of us are aware that our cellphones and cars equipped with a GPS facility do regularly generate signals conveying their geographical position (plus other data characterizing movement, e.g., acceleration and instant speed), not everybody is aware of what may happen later to this data, that is, how it can be used, by whom, and for what purpose. This book aims to introduce the potential answers to this question. The presentation of the material aims to make the book an easy read for all professionals (students included) in computer sciences and geoinformatics. Special attention has been given to show enough examples to optimize the understanding of the discussions. Moreover, application-oriented chapters have been included to illustrate a number of existing application domains that already benefit from using mobility data. All topics are covered to the level of detail that is compatible with a reasonable length of the book.

While the ultimate goal in mobility data processing is to solve high-level issues such as understanding how, when, where, and ultimately why objects (including persons and animals) move, elaborating the answer to these questions relies on a complex, multistep process, where the data sent by the data acquisition

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device (e.g., a GPS/GSM device) are analyzed and transformed to be gradually turned into something readily meaningful for the targeted application. This process is sometimes referred to as the *Knowledge Discovery* (KD) process: from raw data to knowledge.

This book first offers an overview of the KD process as applied to mobility data. Each chapter from 1 to 8 discusses one of the issues involved.

Chapter 1 introduces the reader to the basic concepts and terms to deal with mobility data. Namely, the concept of trajectory is defined together with the various ways to approach this fundamental concept. Chapter 2 explains the most important techniques that can be used to collect the raw data from the acquisition devices and transform, homogenize, and prepare it for efficient use by applications, consistently with the application requirements. This includes potential modification of the raw data (e.g., anonymization and obfuscation) to meet privacy requirements. Chapter 3 focuses on how to store the mobility data in a database so that users can benefit from the existing know-how in database management. This is extremely important for this data to become operational with no delay. Chapter 4 similarly investigates the issues for storing mobility data in a data warehouse, opening to its use for decision-making applications interested in aggregated levels of knowledge rather than the detailed level of individual trajectories. Chapter 5 is specifically devoted to addressing the uncertainty issues that are inherent to mobility data, given that position measurements are affected by observational error and thus not necessarily as precise as applications would like them to be. The chapter closes the review of the basic data processing techniques needed for mobility data management.

With Chapter 6 the reader fully enters into the core of the knowledge management process (Part II of the book), that is, how to analyze the collected data to find its aggregated characteristics that can be of interest to the applications at hand. Movement patterns or trajectory behaviors are the core concern of the chapter. However, the lack of semantics of the extracted patterns makes the interpretation task far from obvious. To solve the mismatch following, Chapter 7 introduces the semantic dimension, thus closing the gap between the application quest for mobility information and the knowledge extracted from the data. The identification of semantic behaviors of the moving objects holds the final result of the KD process. Chapter 7 also presents a system, M-Atlas, which supports the whole mobility knowledge discovery process. Chapter 8 closes the knowledge extraction part of the book by showing through many illustrations how visualization of mobility data can be a very effective analysis tool to detect trends as well as singularities.

The last chapter in Part II of the book, Chapter 9, addresses the privacy issue, that is, how to ensure that mobility data do not violate the privacy regulations and constraints that aim at protecting individuals from the undue disclosure of personal data. This represents a very important concern as mobility data related



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to moving persons can reveal details of the person's life that nobody wants to see exposed to public view. Moreover, as users of cellphones and computers we have very little control over what happens to the data that these electronic systems collect, most frequently without making us aware of the hidden data collection routines.

Part III of the book details a number of application examples that show the reader concrete uses of mobility data in a variety of domains. This part starts with the most frequently quoted application domain: car traffic. Obviously the popularity of this application domain is due to the relative ease of getting massive volumes of data from the GPS-equipped cars that have become available in recent years. Chapter 10 shows traffic application results from a variety of data repositories.

Chapter 11 is also devoted to traffic analyses, but its moving objects are boats and the moving space is the sea. This leads to a context that is quite different from cars moving in a city, as navigation rules and paths for boats are different from those of cars. The environmental data are quite different: cities show plenty of landmarks to which a human trajectory can be linked, and the same landmark (e.g., a commercial centre) can host a multiplicity of facilities that can be targeted by a moving person. Instead, the destination of a boat can usually be recognized without ambiguity, while its path is not arbitrary and has to avoid potentially hidden obstacles.

Chapter 12 closes the analysis of transportation means showing an air traffic control application, in which a variety of data sources, for example, meteorological data, have to be combined with trajectories of planes with very strong security constraints. The interesting feature of this application domain is its use of visualization tools that play an essential role in facilitating faster decision making.

Ecology is another very popular application domain that largely benefits from the availability of movement data. Chapter 13 discusses the evolution of scientific approaches to modeling animals' movement, from the formulation of the first hypotheses to modern mathematical models supporting statistical studies. It also discusses the devices that are used today for data acquisition of animals' movement.

The next application chapter, Chapter 14, covers aspects of human movement. Human movement has several unique features, such as unconstrained routes, unpredictability and sudden changes, variety of transportation means, and a richer variety of reasons for moving than animals have. In some contexts (e.g., large pedestrian crowds), traditional means of measuring mobility will not suffice for quantitative analyses. The chapter introduces the Bluetooth tracking methodology and some of its benefits in comparison with other methodologies. Despite the coarse nature of the data, exciting analyses such as crowd size estimations, flow analysis, pattern discovery, and profiling are possible.

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Part IV concludes the book with three more chapters. The aim of this part is to introduce the newest developments that call for new forms and new uses of mobility data. Chapter 15 explores how the recent developments of network sciences can be applied to enriching mobility analysis approaches. This is a recent combination of scientific domains that together can significantly enhance our ability to understand movement. The second prospective chapter, Chapter 16, explores the peculiar forms of mobility data that can be gathered thanks to the popularity of social networks. Social network data is not necessarily in terms of trajectories, yet it implicitly conveys data about the movement of people. How to intelligently extract these data and analyze them is a new and exciting challenge. At last, the concluding Chapter 17 outlines some directions for future research in view of future applications. Obviously these are just a few examples; the real potential is huge.

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