TUP-Springer **Project**

Xiaofeng Meng
Zhiming Ding
Jiajie Xu

移动对象管理

模型、技术与应用（第2版）

Moving Objects Management

Models, Techniques and Applications

2nd Edition

清华大学出版社 Springer

Xiaofeng Meng
Zhiming Ding
Jiajie Xu

移动对象管理

模型、技术与应用（第2版）

Moving Objects Management

Models, Techniques and Applications

2nd Edition

清华大学出版社
北京

Springer

内 容 简 介

移动通信技术的持续发展催生了基于位置服务（LBS）的广泛应用。这类新型应用需要存储并管理移动对象不断变化的位置信息。本书针对移动对象数据管理问题，从位置服务的角度分析频繁的位置变化给传统数据库所带来的挑战。本书系统介绍了移动对象建模与位置跟踪、索引、查询处理与优化、轨迹聚类、不确定性处理、隐私保护等领域的最新研究成果，以及相关成果在智能交通系统中的应用。

本书的读者对象为高等院校计算机专业的本科生、研究生、教师，科研机构的研究人员以及相关领域的开发人员等。

图书在版编目(CIP)数据

移动对象管理：模型、技术与应用：英文/孟小峰，丁治明，许佳捷著. -- 2 版. --北京：清华大学出版社，2014

ISBN 978-7-302-32286-3

I.①移…　II.①孟…②丁…③许…　III.①移动通信–数据管理–英文　IV.①TN929.5 ②TP311.13

中国版本图书馆 CIP 数据核字(2014)第 091773 号

责任编辑： 薛　慧
封面设计： 何凤霞
责任印制： 沈　露

出版发行： 清华大学出版社
网　　址： http://www.tup.com.cn, http://www.wqbook.com
地　　址： 北京清华大学学研大厦 A 座　　**邮　　编：** 100084
社 总 机： 010-62770175　　**邮　　购：** 010-62786544
投稿与读者服务： 010-62776969, c-service@tup.tsinghua.edu.cn
质量反馈： 010-62772015, zhiliang@tup.tsinghua.edu.cn
印 装 者： 三河市中晟雅豪印务有限公司
经　　销： 全国新华书店
开　　本： 153mm×235mm　　**印张：** 15.5
版　　次： 2010 年 5 月第 1 版　2014 年 9 月第 2 版　　**印次：** 2014 年 9 月第 1 次印刷
印　　数： 1～1000
定　　价： 78.00 元

产品编号：052792-01

Preface

The widespread use of mobile positioning tools like GPS and smart mobile phones nowadays has aroused great interests in location-based services (LBS) that have to store and manage continuously changing positions of moving objects. This book gives a comprehensive and complete view of a moving objects database and introduces how it is used in LBS and transportation applications. It aims at moving objects management, from the location management perspective to analyze how the continually changing locations affect the traditional database and data mining technology. Specifically, the book describes the cutting edge technologies related to topics like moving objects modeling and location tracking, indexing and querying, trajectory prediction, location uncertainty, traffic flow analysis, objects clustering, traffic aware navigation and privacy issues as well as their application to intelligent transportation systems.

Previous studies mostly focused on moving objects database in free space. They assumed that the movement of the objects is unconstrained and based on Euclidean spaces. However, in the real world, objects usually move within spatially constrained networks, e.g., vehicles move on road networks. Overlooking this reality often leads to unrealistic data modeling and inaccurate query results. The content in this book focuses mainly on the moving objects within spatial networks, which is more practical. By exploiting the network feature of spatial networks, this book introduces models, techniques, and applications of moving objects management in a spatial network.

This book is intended to help readers understand the main technologies in moving object management and apply them to LBS and transportation applications. Compared with the first edition, this book particularly focuses on the constrained network environments, and it has made substantial changes to each chapter so that the cutting edge techniques in this field are included. With its accessible style and emphasis on practicality, the book presents new concepts and techniques for managing continuously moving objects. Database management systems developers, mobile applications developers, and applied R&D researchers will find the study an essential companion for new concepts, development strategies, and application models associated with this kind of changing location data. The book:

- Presents a comprehensive architecture of moving object management, which includes not only basic theories and new concepts but also practical technologies and applications
- Describes a set of new database techniques in modeling, tracking, indexing, querying of moving objects, traffic flow analysis, as well as data mining techniques in clustering analysis of moving objects
- Introduces some new research issues in location privacy and uncertainty management of moving objects, which are topics of major interest in this field
- Provides typical applications of moving objects management in intelligent transportation systems

Organization of the Book

This book contains 12 chapters, which describe the problems, models, techniques, and applications of moving objects management. It is organized as follows:

In Chap. 1, we introduce some background of moving objects management, including its concept and applications. Finally we present the main content: key technologies of moving objects databases and our focus in this book.

In Chap. 2, we introduce some underlying modeling methods and present two moving object models that can reflect real-time traffic conditions of the road network. The first one is the DTNMOM, which considers the dynamics of underlying road network. And for the second model called ARS-DTNMOM, we introduce the concept of atomic route section and define its corresponding data types and operations in database.

In Chap. 3, we introduce a few underlying methods on moving object tracking. Then, we describe three representative network-constrained location update strategies (Net-LUM, ANLUM, and EuNetMOD), which can achieve better performances in terms of communication costs and location tracking accuracy.

In Chap. 4, we first introduce a few of the underlying spatial index structures including the R-tree, TPR-tree, spatio-temporal R-tree, trajectory-bundle tree, and MON-tree. Then, we propose two new index methods that are used for indexing frequently updated trajectories of network constrained moving objects and indexing the whole trajectories with historical, current, and near future positions, respectively.

In Chap. 5, we classify the basic querying types for moving objects according to spatial predicates, temporal predicates, and moving spaces. Then, we introduce how to process a range query and a kNN query in a spatial network, based on the Euclidean restriction and network expansion frameworks.

In Chap. 6, we introduce advanced querying for moving objects including similar trajectory queries and density queries for moving objects in a spatial network. We first present how to process the snapshot density queries. Then, we introduce some efficient methods based on the safe interval to continuously monitor dense regions for moving objects.

In Chap. 7, we first review some linear prediction methods and analyze their limitations in handling moving objects in spatial networks, then present the simulation-based prediction methods: fast-slow bounds prediction and time-segment prediction, and finally present an uncertain path prediction method which can predict future trajectories based on the uncertain historic trajectories of moving objects in spatial networks.

In Chap. 8, we study the uncertainty management problem for moving objects databases with a few uncertainty models. Then we introduce a novel framework that can manage uncertainty trajectory effectively and answer queries about them accurately; particularly, we focus on the key technical issues like uncertain trajectory modeling, database operations, and query processing of uncertainty management.

In Chap. 9, we study the underlying researches and inherent problems in traffic behavior analysis based on moving object trajectories. Then we firstly propose a new model for objects moving on dynamic transportation networks (MODTN), based on which we introduce a real-time traffic flow statistical analysis method (NMOD-TFSA).

In Chap. 10, we introduce the clustering analysis of moving objects in spatial networks. After that, we introduce two new static clustering algorithms, which use the information of nodes and edges in the network to improve the clustering efficiency and accuracy. Then, we introduce the notion of cluster block (CB) as the underlying clustering unit and propose a unified framework of clustering moving objects in spatial network (CMON), which improves the dynamic clustering performance of moving objects and supports different clustering criteria. Finally, we introduce two trajectory clustering algorithms which use the partition-and-group framework for clustering trajectories and a filter-refinement framework for hot region discovery, respectively.

In Chap. 11, we present another application, traffic aware route navigation, with a new traffic aware route planning model based on incremental planning method introduced. By selecting intermediate destinations, a partial path rather than whole path is planned each time for long distance queries. In this way, route planning is more efficient because it is carried out in a much smaller region, and unnecessary re-calculations caused by the dynamic road conditions can be avoided.

In Chap. 12, we introduce location privacy, and analyze the challenges of preserving location. Then, we provide an analysis of the current studies including the system architecture, location anonymity, and query processing.

As shown in Fig. 1, the contents of the whole book construct a comprehensive moving object management and application system. Figure 1 also shows the relationship of each component in the system.

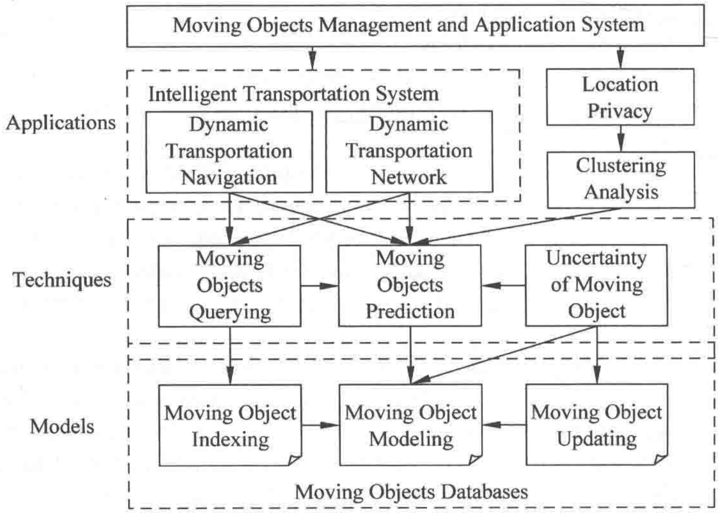

Fig. 1 Organization of the book

Acknowledgments

The work described in this book has been supported by the grants from the Natural Science Foundation of China (No. 61379050, 91024032, 91124001, 91224008); the National 863 High-tech Program (No. 2013AA013204); and Specialized Research Fund for the Doctoral Program of Higher Education (No. 20130004130001).

This book is based on the research work of the authors for over 15 years. The book integrates the collective intelligence from the mobile group of the WAMDM Lab (Lab of Web and Mobile Data Management) at Renmin University of China, and the database group of NFS Center (The National Engineering Research Center of Fundamental Software) at Institute of Software, Chinese Academy of Sciences. The authors would like to express their great thanks to all the people who contributed to this book, including Dr. Jidong Chen, Dr. Xiao Pan, Dr. Limin Guo, Dr. Kuien Liu, Dr. Haoming Guo, Xing Hao, Zhen Xiao, and Rui Ding. In particular, the authors wish to thank Dr. Jidong Chen, Dr. Xiao Pan, and Dr. Limin Guo for their valuable efforts on this book.

Beijing, China
December 2012

Xiaofeng Meng
Zhiming Ding
Jiajie Xu

Acronyms

ADT	Abstract data type
ANN	Aggregate nearest neighbor
AU	Adaptive unit
CA	Cellular automaton
CN	Cluster node
CU	Cluster unit
DS	Dense segment
DSS	Dense segment set
DTTLU	Distance-threshold triggered location update
DyNSA	Dynamic navigation system based on moving objects stream aggregation
GCA	Graph of cellular automata
GPS	Global positioning system
HAT	Hierarchy aggregation tree
IER	Incremental Euclidean restriction
INE	Incremental network expansion
ITLU	ID-triggered location update
LBS	Location-based service
LP	Linear prediction
MBR	Minimum bounding rectangle
MO	Moving object
MOD	Moving objects databases
MODTN	Moving objects on dynamic transportation networks
MOST	Moving objects spatio-temporal
MRM	Mobile resource management
NN	Nearest neighbor
PDQ	Period density queries
PTSS	Prediction with time-segmented
QoS	Quality of service
RER	Range Euclidean restriction
RNE	Range network expansion

Contents

Chapter 1
Introduction

Abstract The fast development of geo-positioning and wireless sensor network technologies has aroused widespread use of location-based services (LBS), which provide useful location-dependent information to users. LBS have become so important nowadays that people rely on it to plan trip, book cabs, and find share car partners. Moving objects database, which plays a key role in supporting LBS applications, has attracted great attention from both academy and industry in recent years. In this chapter, we introduce the concept of moving object data management first and then describe the wide applications of location-based service. Key techniques related to moving objects database are discussed and analyzed afterwards. After that, we mention the purpose and organization of this book.

Keywords Mobile computing • Location-based service • Moving objects management • Moving object databases • Model • Index • Query • Update • Prediction • Uncertainty management • Clustering • Traffic statistical analysis • Traffic navigation • Location privacy

1.1 Concept of Moving Objects Data Management

The general idea of moving object data management is to represent the moving entities in databases and process queries about them efficiently. Moving entities could be human, animals, all kinds of vehicles like cars, trucks, air planes, ships, etc., and people often issue queries about their location, such as finding all vacant taxicabs inside a requested spatial area. However, existing database management systems (DBMSs) are not well equipped to handle the massive dynamic location data sampled from moving objects. Therefore, moving objects database (MOD), which particularly includes the management of the moving objects location and related information, has become an enabling technology that can find various LBS applications nowadays.

X. Meng et al., *Moving Objects Management: Models, Techniques and Applications*, DOI 10.1007/978-3-642-38276-5_1,

Moving objects database belongs to the area of spatio-temporal databases, which in turn have its root in spatial database, dealing with descriptions of geometry in databases, and temporal database, addressing the development of data over time. The major difference between them is that moving objects database focuses on the continuous spatial position change with time (their movement is seen as trajectory), while other spatio-temporal databases only support the discrete changing of spatial information for all moving entities in database.

We can actually understand the idea of moving objects database from two different perspectives. Firstly, moving objects database is to represent, store, index, and query on the continuously changing locations of moving objects and to predict the future positions of them; secondly, the focus is to store the whole history of moving object movement in database, so as to answer queries on the location of moving objects at any instance (including both history and future). Essentially, the former approach is to analyze from the location management perspective, while the second one stands on the spatio-temporal data perspective. As a result, research on moving objects database can be made from two aspects as well: location management view and spatio-temporal data view.

The key problem of MOD is how to manage the locations of a set of moving objects in database, e.g., position of all taxicabs inside a city road network. Given a time instance, it is not a problem. However, as the taxicabs move, it is necessary to have the location frequently updated, so that we can derive its current location. Here we encounter an unpleasant trade-off between update cost and location precision. From the data management perspective, MOD focuses on issues like how to manage the information of moving objects location dynamically and how to process different types of complex queries about current and future positions efficiently.

So far, considerable research has been carried out on moving object data management. In the following sections, we introduce some typical applications and key technologies related to MOD, including the modeling and tracking of location information, spatio-temporal indexing, uncertainty management, query processing, trajectory data mining (including traffic flow analysis), and privacy issues.

1.2 Applications of Moving Objects Database

Moving objects database is a fundamental technique for LBS, from which people can get useful information and entertainment services through mobile devices. In a typical LBS application, moving objects use e-services that involve location information. The objects disclose their positional information (position, speed, velocity, etc.) to the services, which in turn use this and other information to provide specific functionality. The following five categories described next characterize what may be thought of as standard location-based services; they do not attempt to describe the diversity of services possible [28].

1. Traffic coordination and management: Based on past and up-to-date positional data on the subscribers to a service, the service may identify traffic jams and determine the currently fastest route between two positions; it may give estimates and accurate error bounds for the total travel time, and it may suggest updated routes for the remaining travel. It also becomes possible to automatically charge fees for the use of infrastructure such as highways or bridges (termed as road pricing and metered services).
2. Location-aware advertising and general content delivery: Users may receive sales information (or other content) based on their current locations when they indicate to the service that they are in "shopping mode." Positional data is used together with an accumulated user profile to provide a better service, e.g., advertisements that are more relevant to the user.
3. Integrated tourist services: This covers the advertising of the available options for various tourist services, including all relevant information about these services and options. Services may include overnight accommodation at campgrounds, hostels, and hotels; transportation via train, bus, taxi, or ferry; and cultural events, including exhibitions, concerts, etc. For example, this latter kind of service may cover opening-hour information, availability information, travel directions, directions to empty parking, and ticketing. It is also possible to give guided tours to tourists, e.g., that carry online cameras.
4. Safety-related services: It is possible to monitor tourists traveling in dangerous terrain and then react to emergencies (e.g., skiing or sailing accidents); it is possible to offer senile senior citizens more freedom of movement and a service that takes traffic conditions into account to guide users to desired destinations along safe paths.
5. Location-based games and entertainment: One example of this is treasure hunting, where the participants compete in recovering a treasure. The treasure is virtual, but is associated with a physical location. By monitoring the positions of the participants, the system is able to determine when the treasure is found and by whom. In a variation of this example, the treasure is replaced by a "monster" with "vision," "intelligence," and the ability to move. Another example in this category is a location-based ICQ service.

1.3 Key Technologies in Moving Objects Database

1.3.1 Moving Objects Modeling

The modeling of moving object in databases is a basic technique for MOD. In conventional databases, attribute values stored in table are assumed to be constant unless they are explicitly updated. However, in MOD, the location of moving object changes continuously, and people issue queries to find their history, current, and even future position. As conventional database models are unable to represent dynamic location information, moving objects modeling plays an important role in effective location management. Current research on MOD modeling can be generally classified into two categories: Euclidean (EU)-based modeling and network (NET)-based modeling.

EU-based modeling targets to represent the trajectories of free movement objects in Euclidean space. Wolfson et al. propose a moving objects spatio-temporal (MOST) model in [43, 51] first. Its core idea is to consider location of moving objects as a dynamic attribute, which is represented as a function of time. In this way, we do not need to update this attribute until this function is no longer valid. However, long trajectories cannot be well supported by the MOST model because of the limited representation capacity of simple functions. Later, Forlizzi et al. in [19] present a discrete moving object data model to overcome this drawback, with a feasible solution for complex moving object trajectory representation. Also, models like linear constraint [45], abstract data types [25], and space-time grid storage [11] are proposed. However, these EU-based models do not take into account the network constraint, while objects move with road network constraint in most real-life applications, especially for the vehicles in transportation scenarios.

As moving objects move according to the topology of underlying road network, the interaction between modeling and network structure enables better object movement representation, and this contributes to improve the performance of object tracking, data indexing, and query processing. To represent the movement of objects under road-network constraint, we need to model the road network first and then to model how the objects move on this network. Static road network can be generally represented in three ways: road-based representation, two-dimensional geographic coordinate-based representation, and graph-based representation. For the moving objects on road network, we can further use road segment and trajectory to model the movement of objects.

Vazirgiannis et al. propose a road-network-based moving object model that combines the trajectory with road network in [49], where road network is represented as a digital map and trajectory is represented as the path from starting point to destination. In recent years, some other network constraint models based on graph representation such as [24, 37, 44] have been proposed. But they simply assume linear movement and cannot reflect the real movement feature of moving objects in a road network, and they only consider static transportation networks. That limits their applicability in a majority of real-life applications. An advanced model is also proposed in [46] to integrate the past movement features to improve the capability of moving object representation.

1.3.2 Location Tracking of Moving Objects

In moving objects tracking, current position is periodically sent to the central server and stored in database. When the number of tracked moving objects becomes large,