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移动对象管理
模型、技术与应用

Moving Objects Management
Models, Techniques and Applications

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内 容 简 介

随着移动通信技术的不断发展和普及，人们对移动对象管理的需求越来越迫切。移动对象管理成为数据库研究领域的一个热门方向，它在许多领域都展现了广阔的应用前景。本书比较系统地介绍了移动对象管理的相关内容，即移动对象管理模型（包括移动对象建模、移动对象更新、移动对象索引等），移动对象管理技术（包括移动对象查询、移动对象预测、移动数据不确定性研究等），移动对象管理应用（包括动态交通导航、动态交通网络、移动对象聚类分析、位置隐私保护等）。

本书总结了国内外有关移动数据管理的研究工作和具有代表性的关键技术，并较详细地介绍了作者近年来的一些研究成果，具有较大的参考价值。

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。

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Foreword

We live in an age of rapid technological development. The Internet already affects our lives in many ways. Indeed, we continue to depend more, and more intrinsically, on the Internet, which is increasingly becoming a fundamental piece of societal infrastructure, just as water supply, electricity grids, and transportation networks have been for a long time. But while these other infrastructures are relatively static, the Internet is undergoing swift and fundamental change: Notably, the Internet is going mobile.

The world has some 6.7 billion humans, 4 billion mobile phones, and 1.7 billion Internet users. The two most populous continents, Asia and Africa, have relatively low Internet penetration and hold the greatest potentials for growth. Their mobile phone users by far outnumber their Internet users, and the numbers are growing rapidly. China and India are each gaining about half a dozen million new phone users per month. Users across the globe as a whole increasingly embrace mobile Internet devices, with smart phone sales are starting to outnumber PC sales. Indeed, these and other facts suggest that the Internet stands to gain a substantial mobile component.

This mega trend towards "mobile" is enabled by rapid and continuing advances in key technology areas such as mobile communication, consumer electronics, geo-positioning, and computing.

In short, this is the backdrop for this very timely book on moving objects by Xiaofeng Meng and Jidong Chen.

The mobile Internet differs from the conventional Internet in key respects. Its users are faced with much more varied use situations: Rather than being in the office or at home, they are engaged in diverse activities such as driving or using public transport, walking, or attending a meeting. The mobile setting calls for a much more varied collection of services and applications, many of which will push content to their users when certain conditions are met. It becomes increasingly important to be able to anticipate the user's current needs. A key signal in this regard is the user's geo-context, notably the user's current location. Thus, user location is fundamentally important for the mobile Internet.

Meng and Chen's book concerns data management for moving objects on the mobile Internet. This important area is subject to intense research by a large and global community of scientists. And due to its many and diverse contributions, this area is also often confusing: it is difficult to attain an overview of important topics and solutions.

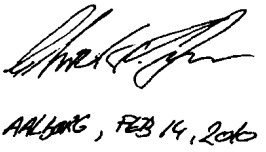
I am excited about the book because it — by its very choice of topics and its coverage of these — offers structure to this rapidly evolving area. It introduces the reader to key tropics in data management for moving objects, offering both overviews and covering specific techniques in considerable detail. The book covers modeling, query processing techniques, and applications.

The book considers the representation of the positions of moving objects and the modeling of the underlying space in which the objects move. Since object movement is frequently constrained to a transportation network, the book affords this setting special attention throughout. It addresses the problem of maintaining up-to-date representations of the objects' positions. It also considers the important problem of indexing a database of frequently updated moving-object positions, including the current positions and the past, current, and anticipated future positions stored in an evolving database, as well as the past trajectories stored in a static database.

On this foundation, the book delves into query processing, covering the fundamental *k*NN and range queries and also similar-trajectory retrieval and one-time and continuous density queries. It covers solutions to the problem of predicting the future trajectory of a moving object, and it addresses the topic of position uncertainty. Moving on to applications, the book puts focus on dynamic vehicle navigation, data management in dynamic transportation networks, and real-time moving-object clustering. The book ends with a coverage of location privacy.

The book meets the need for a coherent account of the state-of-the-art on important topics in the area of moving-object data management, which is at the core of the evolving mobile Internet. It comes highly recommended to research students and researchers new to the topics covered, as well as to experienced researchers.

AALBORG, FEB 14, 2010 *Christian S. Jensen*



Preface

The continued advances in wireless communications and positioning technologies such as global positioning systems (GPS) enable new data management applications such as location-based services (LBS) that store and manage the continuously changing positions of moving objects. This book gives a comprehensive and complete view of a moving object management system. 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 moving objects management from every aspect including moving objects modeling, location updating and indexing, querying and prediction for moving objects, uncertainty management, clustering analysis, location privacy issue, as well as some applications in intelligent transportation management.

Early studies 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 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. The book is intended to help readers understand the main technologies in moving object management and apply them to LBS and transportation applications.

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, indexing, querying and updating locations of moving objects, 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 two typical applications of moving objects management in intelligent transportation systems.

Organization of the Book

The book contains three parts with a total of twelve chapters, which describe the models, techniques, and applications of moving objects management. It is organized as follows:

The first part describes the underlying data models of moving objects management, including location modeling, location updating, and moving object indexing.

In Chapter 1, we introduce some background of moving objects management, including mobile computing and positioning technique, and then describe some applications in location-based services and mobile data management. Finally we present the main content — the moving objects databases technologies and our focuses in this book.

In Chapter 2, we introduce a few underlying location modeling methods and propose a new graph of cellular automata (GCA) model to integrate the traffic movement features into the model of moving objects and the underlying spatial network.

In Chapter 3, we first introduce a few of the underlying spatial index structures including the R-tree, Grid File, and Quad-tree. Then, we propose the indexing methods for moving objects in Euclidean space and in spatial networks, respectively. Finally, we describe techniques that index the past, present, and anticipated future positions of moving objects.

In Chapter 4, we introduce a few underlying location update methods. Then, we describe two location update strategies in detail, the proactive location update strategy and group location update strategy, which can improve the performance.

The second part describes the key techniques of moving objects management, in particular the query processing, location prediction, and uncertainty management.

In Chapter 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 Chapter 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 Chapter 7, we first review some linear prediction methods and analyze their limitations in handling moving objects in spatial networks, and finally present the simulation-based prediction methods: Fast-Slow Bounds Prediction and Time-Segment Prediction.

In Chapter 8, we study the uncertainty management problem for moving objects databases with uncertainty models and indexing algorithms. We propose an uncertainty model and an index framework, the UTR-Tree, for indexing the fully uncertain trajectories of network-constrained moving objects.

The third part describes some typical applications of moving objects management, e.g., dynamic transportation navigation and dynamic transportation networks. Some advanced applications like location privacy and clustering analysis of moving objects are also introduced.

In Chapter 9, we first discuss the kind of applications that can be built based on moving objects management technologies. Then, a typical application in an intelligent transportation system, dynamic transportation navigation, is described in detail, which can provide the user, always in real time and in a continuous fashion, the optimal path to the destination considering the traffic conditions.

In Chapter 10, we present another application, a new moving objects model and query system for moving objects on dynamic transportation networks (MODTN). In MODTN, moving objects are modeled as moving graph points that move only within predefined transportation networks and the underlying transportation networks are modeled as dynamic graphs so that the state and the topology of the graph system at any point in time can be tracked and queried.

In Chapter 11, we introduce an advanced application, clustering analysis of moving objects in spatial networks. We first propose 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 a 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.

In Chapter 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. 0.1, each chapter of the two parts in this book can be treated as one component of a typical moving objects management system. The contents of the whole book construct a comprehensive moving object management and application system. Figure 0.1 also shows the relationship of each component in the system.

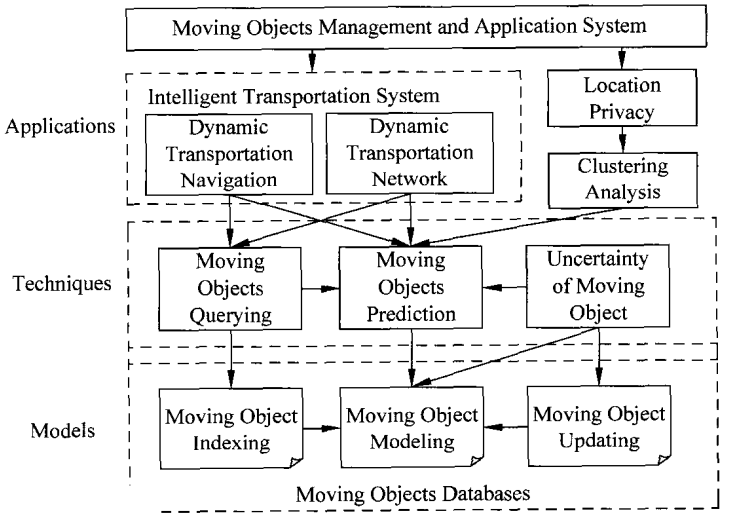


Fig. 0.1 Organization of the book

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This book is based on the research work of the authors in the past years, including the Ph.D thesis of Dr. Jidong Chen accomplished in June 2007 at Renmin University of China. The book integrates the collective intelligence from the mobile group of the Lab of Web and Mobile Data Management (WAMDM) at Renmin University of China. The authors would like to thank all the people in the group, Zhiming Ding, Xiao Pan, Xing Hao, Rui Ding, Yun Bai, Yanyan Guo, Benzhao Li, Zhizhi Hu, Zhen Xiao, Caifeng Lai, Shaoyi Yin and Yulei Fan. In particular, the authors appreciate Xing Hao, Xiao Pan and Yulei Fan for helping the collection and organization of the materials.

Beijing, China,
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Acronyms

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
RNN	Reverse nearest neighbor
SDQ	Snap-shot density queries

SP Simulation-based prediction
STTLU Speed-threshold triggered location update
UT-Unit Uncertain trajectory unit
UTR-Tree Uncertain trajectory R-tree

Contents

Part I
Moving Objects Management Models

Mobile data management has attracted considerable attention. Moving objects databases that manage the locations and corresponding information of moving objects have therefore been developed and have become the technical foundation of many location-based services applications. This part describes the underlying data models of moving objects management, including location modeling, location updating, and moving object indexing.

In the first chapter, we introduce some background of moving objects management, including mobile computing and positioning technology, and then describe some applications in location-based services and mobile data management. Finally, we present the main content of moving objects databases technologies and our focuses in this book.

Location modeling is the foundation for moving objects databases. In Chapter 2, we introduce a few underlying location modeling methods and propose a new graph of cellular automata (GCA) model to integrate the traffic movement features into the model of moving objects and the underlying spatial network. The structure, trajectory, and transition of GCA as well as two-lane GCA are described in detail.

In Chapter 3, a few underlying location update methods are introduced based on thresholds, location prediction, and object grouping. Then, we describe two location update strategies in detail, which can improve the performance. One is the proactive location update strategy, which predicts the movement of moving objects in order to lower the update frequency; the other is the group location update strategy, which groups the objects to minimize the total number of objects reporting their locations.

In Chapter 4, we first introduce a few of the underlying spatial index structures including the R-tree, Grid File, and Quad-tree. Then, we propose the indexing methods for moving objects in Euclidean space and in spatial networks, respectively. Three indexing structures: the time parameterized R-tree (TPR-tree), Grid File-based moving objects index (GMOI), and future trajectory Quad-tree (FT-Quad-tree) are presented to improve the R-tree, Grid File, and Quad-tree index structures for moving objects in Euclidean space. For moving objects in spatial networks, we introduce a dynamic data structure, called adaptive unit and the adaptive network R-tree (ANR-tree) to solve the index update problem and to support predictive querying of moving objects. By naturally extending the ANR-tree to index historical trajectory, it can be used to index the past, present, and future positions of moving objects in road networks. Finally, we discuss how to reduce index updates in existing moving objects indexing structures.