Representation, Analysis and Visualization of Moving Objects

Short report of Dagstuhl Seminar No 08451 (02.11. – 07.11.2008)

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1 Background

This workshop has been organized as a successor to five preceding ones that were centered around topics of computational cartography and geographic information systems. The major goal has been to bring together the still small, but fast growing, research community that is involved in developing better computational techniques for spatio-temporal object representation, data mining, and visualization massive amounts of moving object data. The participants included experts from fields such as computational geometry, spatial databases, GIScience, photogrammetry, spatial statistics, and knowledge discovery and data mining. The majority of participants where from academic institutions, some from government agencies. Several industry representatives were invited, but unfortunately were unable to attend the seminar. However, one of the organizers is from ESRI Inc., the leading GIS company. The seminar has lead to a fruitful exchange of ideas between different disciplines, to the creation of new collaborations, and to recommendations for future research directions (see Section 4).

2 Challenges

Mobility is key in a globalized world where people, goods, data and even ideas move in increasing volumes at increasing speeds over increasing distances. Understanding of mobility patterns and movement behaviors will increasingly become a key factor for success in many businesses such as location-based services (LBS), advertising, and logistics. It will be essential for the prediction and monitoring of individual and group behaviors in response to and mitigation of security threats over short and long time scales. Traffic simulation can greatly benefit from the analysis of movement data, for example through better estimates of key parameters. Finally, mobility patterns of endangered species are prerequisites to devising protective measures in nature conservation and successfully managing interactions between tourism and conservation.

Dynamic geographic objects may include phenomena as diverse as people, animals, vehicles or hurricanes, or the pathways of diseases such as SARS. Data recording the trajectories of MOs stem from a variety of sources, ranging from radio telemetry and GPS to mobile telecommunication devices and geo-sensor networks. Despite the diversity of sources and moving objects involved, movement data have in common that they represent joint recordings of spatial and temporal dimensions and capture motion in trajectories. Hence, it is possible to develop powerful methods for knowledge discovery (KD), by data mining and visual analytics, in movement data that can be suited to the needs of diverse application domains. KD of movement patterns may be performed in real-time (e.g. in geo-sensor networks) or off-line and a posteriori. Furthermore, the purpose may be explanation - e.g., discovering and explaining behavioral patterns of an animal to devise better protection measures. Or it may be prediction - e.g., predicting the next move of an

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object to trigger personalized information feeds in a mobile information system or issue a warning.

The problem is that we are only at the beginning of the evolution of a new research domain. Hence, despite the collection of increasing amounts of data in recent years which can be used in movement tracking, only few methods exist today which have been demonstrated to effectively exploit very large volumes of movement data at different spatial and temporal scales. Recent years have however seen increased interest in the development of such methods, which are currently being developed in a rather piecemeal fashion, and have yet to migrate from research to demonstrate convincing social and commercial benefits.

3 Program Overview

The seminar program was made up of two types of sessions, 'regular' technical sessions that featured talks delivered to a plenary audience, and special sessions with a high degree of interaction (open problems session, breakout sessions). In the following, we will give an overview of the program structure, explaining why we chose to set up the program in this way, and providing a summary of the content. The detailed program structure and the titles of the talks are provided in Section 5.

In the **very first session** every participant had the chance to deliver a brief statement about his/her research interests. This gave, on the one hand, the possibility for everybody to introduce himself/herself to the group; on the other hand, it also helped to prepare for the selection of possible topics for small-group discussion in the breakout sessions. The following topics for **breakout sessions** were subsequently selected by vote in the plenary: 1) Representation of moving objects; 2) sensor networks and decentralized algorithms; 3) KDD on large numbers of moving objects; 4) definitions and taxonomy of movement patterns; 5) geo-simulation; and 6) pitfalls in analyzing the trajectories of moving objects. These topics were then discussed in two sets of breakout sessions, with three parallel groups in each. The first session was scheduled on Tuesday late afternoon, the second one on Thursday morning. Each breakout group was given the task to nominate a rapporteur who was later responsible for reporting back the results of the discussion to the plenary. Thus, it was guaranteed that despite the discussion in parallel groups, everybody was at least able to hear a summary of the discussion; plus, a record was kept of the discussion that could be communicated to non-participants via the seminar proceedings.

In addition to the breakout sessions, an **open problems session** was held on Monday evening after dinner. This special type of plenary session was used to collect a list of small and large open problems that could serve as food for thought for the discussions during the week and beyond.

The **regular technical sessions** were scheduled mainly during the first days of the week, in order to give everybody a fair chance to present his/her work before the breakout sessions started. Hence, the presentations could be used as background in the group discussions. The topics addressed in the presentations covered a wide range of problems in the context of the seminar theme: 1) theoretical underpinnings of moving object research; 2) representation and modeling of trajectories of moving objects (e.g. through space-time prisms or qualitative calculi); 3) trajectory databases; 4) geometric algorithms for problems of trajectory data analysis; 5) decentralized algorithms for geo-sensor networks; 6) simulation of movement of spatial agents; 7) privacy issues in mining trajectory data; 8) application case studies; 9) visualization and visual analytics of trajectory data.

On the final day, a **concluding breakout session** was devoted to discussing possible items for the research agenda, which were subsequently compiled and summarized in the final plenary session. A list of these topics is provided in Section 4.

Due to the efforts of both the presenters and the audience, the disciplinary boundaries were crossed many times and this resulted in stimulating discussions. These took place

immediately after the presentations, during breakout sessions, but also during the breaks in the pleasant environment of Schloss Dagstuhl. Great care was spent when designing the program that sufficient time was available to go into more detailed discussions. This was also greatly appreciated by most participants.

4 Outcomes

Outcomes of the seminar include a collection of abstracts, presentations (slides) and some papers surveying the current state of the art in this field and latest research initiatives (available on the website http://www.dagstuhl.de/08451/Materials/). Similar to the previous seminars of this series, it is expected that new partnerships and collaborations between multi-disciplinary groups will form, further advancing this field with the inclusion of emerging topics. As a first concrete initiative in this direction, a proposal for a European COST Action on "Knowledge Discovery from Moving Objects" was launched (http://www.cost.esf.org). The preliminary proposal has since been accepted and the full proposal will be submitted in January 2009. The Dagstuhl seminar provided plenty of useful inputs for the full proposal, as well as links to researchers who are interested to participate in the proposed COST Action. Most of the Europeans among the participants of Dagstuhl seminar 08451 will also participate in the COST Action.

Another important result of the seminar is the list of past and future research directions that was compiled during the final round of breakout discussions on the last day of the seminar. These topics for the **research agenda** include the following:

Looking back over the past Decade:

- Improvement of qualitative analysis and reasoning → e.g. qualitative spatial reasoning
- Growing awareness of privacy issues
- Access to movement data in an unprecedented way
- Personalization as a concept (especially in LBS)
- Global awareness of the importance of moving object research
- … but we have also become disconnected from the application context (cf. talk by Laube & Purves)

Where we want to be in 10 years:

- Seamless process: We know how to move from data to information to insight and knowledge.
- We have moved from a crisp notion of patterns to a notion that can accommodate fuzziness and integrates statistics.
- For a given problem, we know what data is minimally needed to solve it (i.e. we don't use more than is needed).
- We understand granularity issues in space and time … and we understand the relationship between space and time (metrics).
- We know how to solve problems as locally/decentralized as possible.
- We have ways how to deal with privacy issues.

More concrete goals for the next 2-3 years:

- benchmark data sets, annotated, and with benchmark tasks clearly described
- classification, terminology and definitions for movement patterns
- interaction and collaboration between moving objects (e.g. in traffic systems)
- small meeting in 2009 with the task of formulating the research agenda for a collaborative project

5 Detailed Program

	Talks
	Special sessions: Intro, Open Problems, Break-out groups
	Breaks and leisure

Monday, 3 November 2008

09:00	Intro of participants, selection of topics for break-out discussions		Chair: Rob Weibel
10:30	Break		
11:00	Gudmundsson	Detecting Movement Patterns Among Trajectory Data	Chair:
	Othman	Space, Time and Prisms	Rob Weibel
12:00	Lunch		
14:30	Sack	How to fit in another meeting	Chair:
	Delafontaine	QTC – From Theory to Practice	Monika Sester
	Andrienko N.	A Theoretical Framework for the Analysis of Movement	
16:00	Break		
16:30	Brinkhoff	Generator of Network-Based Moving Objects: Experience of 8 Years	Chair:
	Speckmann	Feed-links for Network Extensions	Monika Sester
	Gold	Voronoi Hierarchies for real-time spatial indexing and paging	
18:00	Dinner		
20:00	Open Problems Session		Chair: Jörg Sack
21:15	End		

Tuesday, 4 November 2008

09:00	Andrienko G.	Spatio-temporal Aggregation for Visual Analysis of Movements	Chair:
	Frank	Functions: A Formalism to Represent Moving Objects	Stephan Winter
	Laube/Purves	Pitfalls in Analyzing the Trajectories of Moving Objects	
10:30	Break		
11:00	Duckham	Decentralized Spatiotemporal Computing & Ambient Spatial Intelligence	Chair:
	Timpf	Simulating Geo-savvy Agents	Ross Purves
	Dodge	Moving Object Trajectory Mining: Trajectory Decomposition	
12:00	Lunch		
14:30	Buchin M.	Trajectory Similarity and Time Dependence	Chair:
	Willems	Visualization of Vessel Trajectories for maritima Safety and Security	Wolfgang Bitterlich
15:30	Break		
16:00	Break-out discussions		Self-organized
18:00	Dinner		

Wednesday, 5 November 2008

09:00	Reports of first break-out sessions (plenary)		Chair:
	Shirabe	Containing a Moving Object in a Network	Rolf Klein
	Winter	Simulating Movement in Networks	
10:30	Break		
11:00	Klein	Motion Planning Using Moving Objects	Chair:
	Kulik	Analyzing Moving Object Data Using Aggregation	Takeshi Shirabe
	Forer	The Role of Space in Reporting and Understanding Movement	
12:15	Lunch		
13:30	Hike/Walk or Visit of Trier		
18:00	Dinner		

Thursday, 6 November 2008

09:00	Break-out discussions (2)		Self-organized
10:30	Break		
11:00	Brenner	Thoughts on Data Acquisition of Moving Objects	Chair:
	Spaccapietra	From Moving Objects to Trajectories	Max Egenhofer
12:00	Lunch		
14:30	Egenhofer	Any Privacy for Trajectories?	Chair:
	Paelke	Looking for ST-Patterns	Lars Kulik
	Quak	A 'MovingPoint' DBMS Type	
16:00	Break		
16:30	Reports of second break-out sessions (plenary)		Chair: Matt Duckham
	Sester: Funding Opportunities (EU FP7 etc.)		
18:00	Dinner		

Friday, 7 November 2008

09:00	Break-out groups:		Self-organized
	Research priorities and achievements in the past? (1/3 of the time)		
	Priorities for the future? Research agenda? Possible joint projects? (2/3 of the time)		
10:30	Break		
11:00	Wrap-up session (Plenary): Bringing it all together		Chairs:
	Synthesis of group discussions		Monika Sester
	Closing		Robert Weibel
12:00	Lunch		