08451 Abstracts Collection
Representation, Analysis and Visualization of Moving Objects
— Dagstuhl Seminar —

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Abstract. From 02.11. to 07.11.2008, the Dagstuhl Seminar 08451 "Representation, Analysis and Visualization of Moving Objects " was held in Schloss Dagstuhl – Leibniz Center for Informatics. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

Keywords. Moving objects, trajectory data mining

08451 Summary Report – Representation, Analysis and Visualization of Moving Objects

This document contains a short report summarizing the background, the program, and the outcomes of Dagstuhl Seminar 08451 on "Representation, Analysis and Visualization of Moving Objects".

Keywords: Moving objects, trajectory data mining

Joint work of: Weibel, Robert; Sack, Jörg-Rüdiger; Sester, Monika; Bitterlich, Wolfgang

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2009/1875

08451 Minutes of Open Problems Session

Summary of the open problems identified in a special session in the evening of the first day of Dagstuhl seminar 08451 on"Representation, Analysis and Visualization of Moving Objects".

Keywords: Moving objects, trajectory data mining

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Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2009/1876

Consolidated Research Priorities

The consolidated list of topics of past and future research priorities (research agenda), after discussion in breakout groups and in the final plenary session.

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 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

Keywords: Moving objects, trajectory data mining

Joint work of: Weibel, Robert

Spatio-temporal Aggregation for Visual Analysis of Movements

Gennady Andrienko (Fraunhofer IAIS - St. Augustin, DE)

Data about movements of various objects are collected in growing amounts by means of current tracking technologies. Traditional approaches to visualization and interactive exploration of movement data cannot cope with data of such sizes. In this research paper we investigate the ways of using aggregation for visual analysis of movement data. We define aggregation methods suitable for movement data and find visualization and interaction techniques to represent results of aggregations and enable comprehensive exploration of the data. We consider two possible views of movement, traffic-oriented and trajectory-oriented. Each view requires different methods of analysis and of data aggregation. We illustrate our argument with example data resulting from tracking multiple cars in Milan and example analysis tasks from the domain of city traffic management.

Full text: see http://geoanalytics.net/and Section <publication> - <conference papers> - IEEE VAST 2008

Keywords: CR Categories and Subject Descriptors: H.1.2 [User/Machine Systems]: Human information processing - Visual Analytics; I.6.9 [Visualization]: information visualization. Additional Keywords: Movement data, spatio-temporal data, aggregation, scalable visualization, geovisualization.

Joint work of: Andrienko, Gennady; Andrienko, Natalia

Full Paper:
http://geoanalytics.net/and

Elements of a Theoretical Framework for Analysis of Movements

Natalia V. Andrienko (Fraunhofer IAIS - St. Augustin, DE)

In order to define the classes of analysis tasks in analysing movement data, we consider the possible objects and levels of the analysis. The objects of the analysis are (1) movement of a single entity; (2) movement of multiple unrelated entities; (3) movement of several or multiple related entities.

The possible levels of analysis are (1) motion, i.e. the process of changing the spatial position; (2) trips, i.e. traveling from one place to another; (3) activities of the moving entities. These levels of analysis differ in the amount of semantics that needs to be involved in the analysis.

We consider examples of three different datasets describing the movement of a single entity, multiple unrelated entities, and multiple related entities and discuss the relevant analysis tasks, possible approaches, and open problems.

Joint work of: Andrienko, Natalia; Andrienko, Gennady

Thoughts on data acquisition of moving objects

Claus Brenner (Leibniz Universität Hannover, DE)

This talk was meant to make the audience aware of current and future acquisition techniques for trajectories and point clouds. Personal navigation systems track our route and some of them already have permanent data connections. Mobile laser scanner platforms can generate geo- and time-referenced point clouds at a rate of one billion points per hour. It is assumed that especially cars with their radar, image, and laser scanner capability will lead to dense and up-to-date mapping of large areas. The conclusions are that

- There will be a hierarchy of acquisition systems ranging from expensive, high accuracy, low update rate to inexpensive, lower accuracy, but high update rate
- In order to get huge amounts of movement data, there is probably less additional sensors to install than we think - huge amounts are already produced by devices in our cars and pockets
- Instead of looking for point movement patterns, we will soon have to look for more complex geometric patterns describing the "world state"
- If we think all this automatically produced data is useful for applications (such as saving energy or reducing traffic deaths), we should think of ways obtaining it without scarifying privacy.

Generator of Network-Based Moving Objects: Experience of 8 Years

Thomas Brinkhoff (FH Oldenburg, DE)

In the paper 'A Framework for Generating Network-Based Moving Objects' (Th. Brinkhoff, GeoInformatica, Vol. 6, No. 2, Kluwer, 2002, 153-180) and a former SSDBM short paper of 2000, a network-based generator was presented. The main features of this generator were recapitulated.

Then, some experiences in the last eight year are discussed and the preliminary results of an analysis of the papers citing both papers are presented. The generator was used by the experiments of about 100 papers.

Keywords: Generator, moving objects

Full Paper:
http://www.fh-oow.de/institute/iapg/personen/brinkhoff/generator/

Trajectory Similarity and Time Dependence

Maike Buchin (Utrecht University, NL)

We present three similarity measures for trajectories and algorithms to compute them. The three similarity measures are motivated by three different applications and crucially differ in the role time dependence plays. The first measure is motivated by hurricane trajectories and it is time dependent, i.e., speed is taken into consideration. The second measure is time independent, i.e, speed is not taken into consideration. We use this similarity measure for detecting commuting patterns. The third similarity measure has a relaxed time dependence, i.e., we allow a lag in time. We use this measure for detecting single file movement.

Keywords: Similarity measures, trajectories, Frechet distance

Joint work of: Buchin, Kevin; Buchin, Maike

QTC - From theory to practice

Matthias Delafontaine (Ghent University, BE)

Spatio-temporal data is usually analysed in a quantitive way. In the past decades however, several calculi and formalisms have been developed in order to represent and reason about space and time in a qualitative way. A relevant calculus in the domain of moving objects, is the Qualitative Trajectory Calculus (QTC) which defines relations between moving point objects (MPOs). This talk focuses on the implementation issues involved in the development QTC-based information system.

Keywords: Qualitative reasoning, moving point objects, implementation

Moving Object Trajectory Mining - Trajectory decomposition algorithm

Somayeh Dodge (Universität Zürich, CH)

This talk presents a methodology that allows to extract movement parameters from the trajectories of different types of moving objects and classify trajectories of unknown MPOs by similarity to the trajectories of previously learned MPOs. The key element of the methodology is an algorithm that decomposes the profiles generated for different movement parameters using variations in sinuosity and deviation from the median line.

Our proposed methodology is useful in several respects. It can help answer the question how similar proxy MPOs are to the corresponding reference MPOs. It can inform developers of pattern recognition and data mining algorithms about

similar and dissimilar types of moving objects, hence allowing to design rigorous algorithm evaluation strategies. It yields relevant movement attributes at the global level of the entire trajectory as well as at the local level of segments of homogeneous movement characteristics, enabling more differentiated parameterization of trajectory simulations.

Keywords: Trajectory mining, movement parameter, moving Object

Joint work of: Dodge, Somayeh; Weibel, Robert

Decentralized spatiotemporal computing and ambient spatial intelligence

Matt Duckham (University of Melbourne, AU)

Computing in distributed systems increasingly occurs somewhere, with that location being integral to computational process itself. For example, geosensor networks (wireless networks of sensor-enabled, location-aware computers monitoring environmental change) are increasingly tasked with responding to queries about patterns and events with spatial and temporal extents. Existing algorithms for complex spatiotemporal analysis and queries almost always adopt a centralized approach to computation, where global spatial data is collated and processed, for example in a spatial database or GIS. By contrast, this talk is concerned with problems of decentralized spatiotemporal algorithms, where local spatial data is processed in the network itself, with no centralized or global control. The aim is to embed the capability to respond to spatiotemporal queries in the network itself, termed "ambient spatial intelligence".

Keywords: Geosensor networks

Ontology for Moving Points/Objects/Change... What can ontology contribute to our debate? Are functions a suitable formalism to represent moving objects?

Andrew U. Frank (TU Wien, AT)

Moving objects have a position for each point in time. This is an injective mapping from time to position and formalized as a function. For practical applications, we know typically the position for some time points and need to interpolate between them. Piecewise linear functions defined only for the intervals between known positions can be used and treated as a single function.

For functions a number of operations are available: point-wise addition, subtraction but also distance between two moving points. These operations must be extended by operations to determine the extrema in the function value (what

was the highest point the plane reached between 11 and 12 o'clock?), projections etc.

Functions for moving points are produced by a functor and are therefore a "principled" extension (in the sense of Mac Lean and Birkhoff). They are directly available in functional programming languages (e.g. Haskell).

Keywords: Ontology

Hierarchical Voronoi diagrams for spatial data indexing and paging

Chris Gold (University of Glamorgan, GB)

Hierarchical Voronoi diagrams may be constructed on the assumption that lower-level generators fall within the higher-level index cells. Careful operations permit navigation across page boundaries, and maintenance of the topological network for large dynamic or kinetic point sets.

Keywords: Voronoi, kinetic, hierarchy

Detecting Movement Patterns Among Trajectory Data

Joachim Gudmundsson (National ICT Australia - Sydney, AU)

Technological advances of location-aware devices, surveillance systems and electronic transaction networks produce more and more opportunities to trace moving individuals. Consequently, an eclectic set of disciplines including geography, data base research, animal behaviour research, surveillance and security analysis, transport analysis and market research shows an increasing interest in movement patterns of various entities moving in various spaces over various times scales.

We are currently running a project at NICTA in Sydney where the goal is to develop algorithms and software tools that can detect user-specified patterns among geospatial trajectories. In this talk I give a brief overview of the area, discuss the problem of defining movement patterns that are useful and efficiently computable, new application areas and the need for collaboration across disciplines.

Keywords: Movemet patterns, algorithms

Motion Planning with Moving Objects

Rolf Klein (Universität Bonn, DE)

We study a situation where objects moving in the plane can be used as carriers, in order to get from one location to another. While on board of a carrier, a person can walk towards a boundary point, to better catch another carrier, and so on.

We show that, in a very simple model, fastest paths can be constructed in linear time, while the computation of laziest paths (i.e. paths where the person's walking is a minimum) is NP-complete.

Keywords: Motion planing, time and space

Joint work of: Berger, Florian; Dehne, Frank; Klein, Rolf; Sack, Jörg-Rüdiger

Analyzing Moving Object Data Using Aggregation

Lars Kulik (University of Melbourne, AU)

In my talk (joint work with Egemen Tanin and Hairuo Xie) I present a new technique, Distributed Euler Histograms (DEHs), to store and query aggregated moving object data. Aggregate queries are important for traffic management applications. We define an aggregate query as a query that asks for certain counting information over a geographic region during a time period. Aggregate queries could ask for the total number of cars that entered the downtown area or for the number of cars that went from suburb A to suburb B. Two aggregate query types are of particular importance: distinct entries to an area and the number of objects in that area. Traffic monitoring systems are vital for safety and traffic optimization. However, these systems may compromise the privacy of drivers if they track the position of each driver with a high degree of temporal precision. We argue that aggregated data can protect location privacy while providing useful information for traffic monitoring. We show that DEHs are significantly more efficient, in terms of communication and data storage costs, than techniques that are solely based on moving object identifiers and more accurate than techniques based on simple histograms.

Keywords: Aggregation, Moving Objects, Privacy, Traffic Monitoring

Full Paper:
http://dx.doi.org/10.1109/MDM.2007.30

Pitsfalls in the Analysis of Moving Object Data

Patrick Laube (The University of Melbourne, AU)

After having looked at the analysis of movement data from a variety of standpoints, we suggested a list of methodological pitfall in the analysis of movement data. The list reflected our own experiences working in the field and our reading of the literature. The pitfalls are: (1) Slippery spaces. Many algorithms and movement patterns assume that the observed processes emerge only from interactions between objects (are hence second order effects). However, crucial influences of the underlying geography are typically ignored. (2) Granularity grief. The granularity, and especially the temporal sampling rate, of trajectory data

may have crucial and often hard to perceive effects in the quantitative analysis of movement. (3) Defective definitions. Many definitions of movement patterns are more inspired by our methodological background than by the needs of domain experts. (4) Delusive dwarves. Early work on designing movement analysis concepts based on small samples and proves now to scale rather poorly. (5) Baffling bias. Very large datasets becoming available are often prematurely assumed to be bias free. (6) Sinful simulations. Simulations always are an abstract model view of a reality and easily may misrepresent reality. With our talk we intended to raise awareness for the many methodological pitfalls in movement analysis and, most importantly, stipulate a discussion in the community about how to overcome such problems.

Keywords: Movement analysis, movement patterns, moving objects

Joint work of: Laube, Patrick; Purves, Ross

Space, time and prisms

Walied Othman (Hasselt University - Diepenbeek, BE)

Hagerstrand modelled moving objects with space-time prisms. Objects that bound people movements between time-stamped locations given speed limit constraints.

In this talk we outline how we adapted the model to fit road networks, where all edges can have diferrent speed limits. Furthermore, we outline how we then proceeded to compute the alibi query in this setting, which determines if two moving objects could have met.

Lastly, we expand our model to support uncertain anchorpoints, instead of certain time-stamped locations and introduce the uncertain prism, where every point can be linked to a likelihood, the fraction of space-time prisms that actually contain that point together with their respective probabilities.

Keywords: Space-time prisms, beads, prisms, uncertainty, flexibility, time-geography

Looking for ST-Patterns

Volker Paelke (Leibniz Universität Hannover, DE)

In many applications the patterns of interest are not known in advance.

In an experimental approach to the analysis of ST datasets we identify relevant patterns by letting a human expert mark visual patterns of potential interest in a visualization of "suitable aggregates" of the raw data. Then similar "patterns" are identified automatically by searching the dataset for similar occurrences. In an iterative process combining search and interaction the user reviews the results and can either draw direct conclusions and annotate the pattern (if

the results are matching the requirements), refine the search pattern (if the results are not yet sufficient) or substitute the visualization of the pattern by some glyph (if the pattern is at a lower level of aggregation and higher levels are of interest).

In this way a hierarchical visualization/generalization and interactive analysis of large ST datasets becomes viable. Current research addresses the aggregation of raw data and effective techniques to mark and model proto-patterns through the user and efficient techniques for searching large ST patterns for such proto-patterns.

Keywords: Patterns, Visualization, Interaction, Learning, Abstraction, Aggregates, Genaralization of ST data

A 'movingpoint' type for a DBMS

Wilko Quak (TU Delft, NL)

Im my talk I present iedas for extending a DBMS with functionality to manage moving point objects efficiently. We start with a number of requirements of which the most important are that the type must: 1. Integrate well with existing spatial types. 2. Is efficient for queries that aggregate in the time dimension as well as for queries that aggregate in the space dimension. A debatable question is whether the type should have built-in support for accuracy of the measurements. 3. It should work well for all types of moving points (from different application domains). The second part of the talk describes a proposal implementation of a movingpoint type in the column-store DBMS MonetDB (monetdb.cwi.nl). It turns out that the extension mechanism pf MonetDB enables an efficient implementation.

Keywords: Spatial temporal DBMS gps moving point

How to fit in another meeting

Jörg-Rüdiger Sack (Carleton Univ. - Ottawa, CA)

To schedule a meeting between participants who are geographically located at different points, requires taking travel time into consideration. Traditional meeting schedulers do not use travel time, but only free meeting time is considered. We describe implementation and theoretical development of several algorithms for a variety of meeting scheduler problems.

Keywords: Meeting scheduling

Containing a Moving Object in a Network

Takeshi Shirabe (TU Wien, AT)

A problem of relocating a group of mobile points (or pursuers) to contain another mobile point (or evader) in a network is considered. It is assumed that it is known where the evader is located at the outset and where it can be at any time later, but not where it will be. An example is initial deployment of police officers in response to a 911 call. There often exists no such strategy that guarantees to contain (and then catch) the evader, because the pursuers are not many enough. Thus this paper presents a heuristic approach, which is based on a simple integer programming model, that seeks a possible relocation of the pursuers by a specified time that minimizes "the degree of containment", i.e. the number of nodes the evader can reach earlier than any pursuer.

Keywords: Pursuit evasion, network, containment

From Moving Points to Trajectories of Objects

Stefano Spaccapietra (EPFL - Lausanne, CH)

This presentation is intended to first show how raw movement data can be turned into semantically meaningful sets of trajectories representing some kind of travel of a moving object. Second, it proposes a basic sets of concepts to identify and characterize trajectory structure (begin, end, stop, move). Third it shows how using traditional database modeling techniques a trajectory can acquire any intended semantics through its links to application objects. Fourth it discusses how to achieve the same semantic enrichment using a modular ontology, with the additional benefit of becoming able to enrich the concept set by dynamically adding new concepts defined by explicit axioms. Finally, it shows examples of queries on semantic trajectories, using either formal languages (DL) or Oracle interfaces.

Keywords: Trajectory modeling, trajectory ontologies, trajectory semantics

Joint work of: Spaccapietra, Stefano; Parent, Christine

See also: Conceptual Modeling of Trajectories, DKE Elsevier

Feed-links for Network Extensions

Bettina Speckmann (TU Eindhoven, NL)

Road network data is often incomplete, making it hard to perform network analysis. This paper discusses the problem of extending partial road networks with reasonable links, using the concept of dilation (also known as "crow flight conversion coefficient").

To this end, we study how to connect a point (relevant location) inside a polygon (face of the known part of the road network) to the boundary so that the dilation from that point to any point on the boundary is not too large. We provide algorithms and heuristics, and give a computational and experimental analysis.

Joint work with B. Aronov, K. Buchin, M. Buchin, B. Jansen, T. de Jong, M. van Kreveld, M. Löffler, J. Luo, and R. I. Silveira.

Full paper appeared in Proc. 16th International Conference on Advances in Geographic Information Systems (ACM GIS), article no. 35, 2008.

Keywords: Road Network, Network Analysis

Joint work of: Aronov, Boris; Buchin, Kevin; Buchin, Maike; Jansen, Bart; de Jong, Tom; van Kreveld, Marc; Löffler, Maarten; Luo, Jun; Silveira, Rodrigo I.; Speckmann, Bettina;

Full Paper:
http://doi.acm.org/10.1145/1463434.1463478

See also: Feed-links for Network Extensions. B. Aronov, K. Buchin, M. Buchin, B. Jansen, T. de Jong, M. van Kreveld, M. Löffler, J. Luo, R. I. Silveira, and B. Speckmann. Proc. 16th International Conference on Advances in Geographic Information Systems (ACM GIS), article no. 35, 2008.

Geo-savvy Agents - understanding geospatial behavior

Sabine Timpf (Universität Augsburg, DE)

GeoSimulation - understanding geospatial behavior - producing behavior patterns as emergent patterns from human-human or human-environment interaction

Keywords: Geosimulation, spatial patterns

Visualization of vessel trajectories for maritime safety and security systems

Niels Willems (TU Eindhoven, NL)

This talk gives an overview of current work in progress of the Visualization group of TU Eindhoven in the Poseidon project (www.esi.nl/poseidon).

Operators of coastal surveillance systems have problems to determine whether ships move normal or abnormal.

We present a convolution method for trajectories, which results in density of attendance per area. Our visualization method presents the density in such a way that we are able to determine highways of ships (shipping lanes) and areas

where ships drop anchor (anchoring zones). By filtering parts of trajectories where ships move slowly, we are able to find ships that disobey one of the rules of the sea: ships move with a high speed in shipping lanes.

(Due to uncertainty of permission of publication of slides, I refer to a poster presented on InfoVis 2008, which is a visualization conference.)

Full Paper:
http://www.win.tue.nl/∼cwillems

Simulating Movements in Networks

Stephan Winter (The University of Melbourne, AU)

Problem and motivation:

Moving agents generate traffic. When we model movements in multi-agent simulations we are interested in traffic patterns, traffic management strategies or individual wayfinding behavior. With other words: we are interested in the emerging patterns in this complex system. To model this system, we do need to capture and represent three parts:

1. A travel network (and there are multiple ways to represent networks: graphs, line graphs, embedded graphs, graphs at different levels of granularity (even hierarchic representations), etc.)
2. 2. Assumptions on traffic demand (sources and sinks). Network theory assumes for its centrality measures travels from everywhere to everywhere.
3. Assumptions on the behavior of agents. Are 'people' really traveling along shortest routes?

First candidates for emerging patterns would be the centrality measures of network theory. Central nodes, we would expect, attract more traffic. In this respect, centrality measures can serve as expected values for frequency counts of passing by agents.

Research questions:

I assume that

- Agents do not necessarily follow the (geometric) shortest path; they have purpose, preferences (incomplete spatial knowledge) and social interactions.
- Agents do not travel equally likely from everywhere to everywhere; any model should reflect an irregular distribution and purposeful behavior. How can this behavior be captured for large numbers of agents? What is a sufficient spatial resolution, a representative sample?
  - different roles / purposes of agents means groups may have different OD matrices
  - Confined environments and boundary effects. E.g., indoors everybody needs to find out of the building, but not everybody needs to reach any room in the building ...

- Agents do travel from where? Ontology of places relates to scale (e.g., address / street segment / street) and to the ecological fallacy, correspondingly.

So, can we use centrality measures to predict or to guide the movements of agents in simulations?

Keywords: Multi-agent simulation, traffic simulation, emerging patterns, network centrality