10491 Abstracts Collection
Representation, Analysis and Visualization of Moving Objects
— Dagstuhl Seminar —

Jörg-Rüdiger Sack[1], Bettina Speckmann[2], Emiel Van Loon[3] and Robert Weibel[4]

[1] Carleton Univ. - Ottawa, CA
sack@scs.carleton.ca
[2] TU Eindhoven, NL
speckman@win.tue.nl
[3] University of Amsterdam, NL
vanloon@uva.nl
[4] Universität Zürich, CH
robert.weibel@geo.uzh.ch

Abstract. From December 5 to December 10, 2010, the Dagstuhl Seminar 10491 "Representation, Analysis and Visualization of Moving Objects" was held in Schloss Dagstuhl – Leibniz Center for Informatics.
The major goal of this seminar has been to bring together the diverse and 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, data mining, visual analytics, GIS science, transportation science, urban planning and movement ecology. Most of the participants came from academic institutions, some from government agencies and industry. The seminar has led to a fruitful exchange of ideas between different disciplines, to the creation of new interdisciplinary collaborations, concrete plans for a data challenge in an upcoming conference, and to recommendations for future research directions.
Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper.

Keywords. Moving objects, Spatio-temporal databases, Spatio-temporal analysis, Movement analysis, Spatial data mining, KDD, Computational geometry, Visual analytics

Dagstuhl Seminar Proceedings 10491
Representation, Analysis and Visualization of Moving Objects
http://drops.dagstuhl.de/opus/volltexte/2011/3087

10491 Summary – Representation, Analysis and Visualization of Moving Objects

This seminar is a successor to the Representation, Analysis and Visualization of Moving Objects seminar in 2008 (seminar 08451). The major goal has been to bring together the diverse and fast growing, research community that is involved in developing better computational techniques for spatio-temporal object representation, data mining, and visualization of massive amounts of moving object data. The participants included experts from fields such as computational geometry, data mining, visual analytics, GIS science, transportation science, urban planning and movement ecology. Most of the participants came from academic institutions, some from government agencies and industry. The seminar has led to a fruitful exchange of ideas between different disciplines, to the creation of new interdisciplinary collaborations, concrete plans for a data challenge in an upcoming conference, and to recommendations for future research directions

Joint work of: Sack, Jörg-Rüdiger; Speckmann, Bettina; Van Loon, Emiel; Weibel, Robert

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2011/3086

Results of the break-out group: Movement Data of Vervet Monkeys

Discussions in this group focused on a particular problem that arises in animal movement ecology: how to link data describing movement (i.e. sequential GPS-coordinates collected on wild and free-ranging animals) with geographical and environmental context (i.e. properties of the internal and external environment within which the animals move). Our case study comprised a spatio-temporal data set on the movement of a group of vervet monkeys (Cercopithecus aethiops) over a twelve months observation period. We focused on two topics: context-aware estimation of home range area and multivariate visualisation of context data.

Keywords: Visualisation

Joint work of: Willems, Erik P.; Buchin, Kevin; Demšar, Urška

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2011/2990

Results of the break-out group: Gulls Data

A classification of gull behaviour was produced by the group, led by domain expert Emiel van Loon, who provided additional context including that gull trips are typically composed of distinct segments, that gull trips are rarely single purpose, and that there is very little diurnal pattern to activities. The classification

produced is not intended to be complete, or non overlapping. Furthermore, the group considered how the attributes in the gulls dataset could be used in algorithms to automatically classify the dataset into distinct spatial patterns, and associate this with gull behaviours.

Keywords: Movement classification, Trajectory segmentation

Joint work of: van Loon, Emiel; Sack, Jörg-Rüdiger; Buchin, Kevin; Buchin, Maike; de Berg, Mark; van Kreveld, Marc; Gudmundsson, Joachim; Mountain, David

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2011/2991

Results of the break-out group: Visualisation

In this group we decided to collect literature that we were familiar with that best illustrated how movement data in the form of trajectories can be visualised.

In this report we categorise methods based on what part of the data space is shown, i.e. geographical space, temporal space or attribute space, some combination thereof or an aggregation in one or more of the space components. Methods that use computational methods for pattern recognition in combination with visual methods form a separate category. However, these categories are only what we came up with during our short discussion and are therefore not fixed, nor are they mutually exclusive (i.e. there is certain overlap of methods) and should be extended/redefined as required in a more exhaustive literature review in the future.

Keywords: Visualisation

Joint work of: Buchin, Kevin; Demšar, Urška; Slingsby, Aidan; Willems, Erik

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2011/2986

Results of the break-out group: Benchmarking

This working group has discussed the possibilities to start developing benchmarking tools for algorithms to analyse movement data. Many basic properties of movement data and derived products from these data are not clearly defined. In addition, analysis algorithms vary with respect to input as well as output data. As a result, it is difficult to evaluate the suitability of different algorithms for application to a given type of data and question. We think there is a need to define clear tests or experiments for this purpose.

Keywords: Benchmarking, Movement Analysis

Joint work of: van Loon, Emiel; Purves, Ross; Weibel, Rob

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2011/2988

Results of the break-out group: Similarity measures

In the group discussions we discussed distance measures focussing on real world applications specifically on domain areas where trajectories have been generated by animals (birds, primates...) and humans in urban areas.

Keywords: Similarity, Movement Analysis

Joint work of: Gudmundsson, Joachim; Miller, Harvey; Silveira, Rodrigo; Versichele, Mathias; van der Spek, Stefan

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2011/2989

Results of the break-out group: GPS-Data of Pedestrians

The work by the group can be divided into two parts: a general discussion about the type of data that is available to analyze pedestrians in urban environment, and a short experiment that consisted in collecting GPS tracks of the people in the group. The data in question is to be used to identify and study activities of pedestrians in city environments. The data that is assumed to be known consists of trajectories of a number of individuals, plus appropriate context data. The context data is recognized as playing a fundamental role for this type of study. Since the focus is on recognizing activities of pedestrians in a city, the places where these activities occur are an essential part of the context. The places of interest can have different extents and types, such as neighborhoods, streets, concrete shops, or even information signs. In addition, the geographical constraints imposed by the city layout cannot be ignored. This includes taking into consideration the street network, which—depending on the scale—will be represented by line or area features. Finally, a number of extra exploratory variables may also be relevant, such as size and opening hours of shops, weather conditions, and demographic data of the individuals (age, gender, motion capacity, etc.).

The group identified a number of basic algorithmic questions that seem to be important when analyzing this type of data. Two major problems that need to be addressed are distinguishing between movements and pauses, and to identify noise due to tracking sensors having poor coverage (e.g. indoors). For the latter, the use of extra data about GPS reception (number of satellites, dilution parameters, etc.) as well as cartographic information seems most appropriate. Finally, the group also noted that when tracking groups of people, the knowledge that the individuals are walking together, in a group, can aid the analysis of the data. It was also recognized that group movement will present particular behavior patterns (waiting for others, stopping to discuss what to do, leading, etc.) that may be of particular interest. In this regard, it is an interesting research question how much extra information can be deduced from the fact of having the trajectories of a group of people, as opposed to independent trajectories. The tracking experiment consisted in recording GPS data from a walk from the venue to the nearby city of Wadern. Each member of the group carried three GPS tracking devices,

each with a different sampling rate. This was in order to analyze the impact of this parameter in the trajectories. The walk included several stops of different lengths, which have been registered as metadata to the trajectory information. The tracks also include going inside several shops, in order to generate indoor GPS readings as well. The data is still to be analyzed.

Keywords: GPS trajectories, Urban Environment

Joint work of: Sester, Monika; Silveira, Rodrigo; Snoeyink Jack; van der Speck, Stefan; Speckmann, Bettina; Weibel, Robert

Results of the break-out group: Aggregation

We discussed different problems that arise when aggregating trajectories: how to segment the input, whether to use original parts of the input trajectories, as opposed to an "averaged" path and how to simplify the aggregated structure. We give examples where these questions are not easily answered.

Keywords: Aggregation, Trajectories, Generalization, Map Generation

Joint work of: de Berg, Mark; Sack, Jörg; Speckmann, Bettina; Driemel, Anne; Buchin, Maike; Sester, Monika; van Kreveld, Marc

Extended Abstract: http://drops.dagstuhl.de/opus/volltexte/2011/2987

Clustering Subtrajectories

Maike Buchin (TU Eindhoven, NL)

Often, trajectory data contains repetetive routes, for instance wildlife migration patterns or commuting patterns. To detect these, we search for clusters of similar subtrajectories in the given trajectories. As similarity measure we choose the Frechet distance, which finds subtrajectories with similar shape but possibly different speed development. We showed that the problem of finding the longest subtrajectory cluster using the Frechet distance is NP-complete. Therefore we turn to polynomial time approximation algorithms. Our algorithms sweep the free space diagram, which is the geometric data structure for computing the Frechet distance. Our algorithms can also be run on 'constrained free space diagrams' which allow for a much broader class of distance measures. These distance measures can be based on other attributes than distance, as for instance time, direction, or domain-specific attributes of matched points.

Joint work of: Buchin, Maike; Buchin, Kevin; Gudmundsson, Joachim; Löffler, Maarten; Luo, Jun

Keywords: Moving Object Analysis, Clustering, Movement Patterns

Improving Traffic Flow by Local Methods

Sandor Fekete, (TU Braunschweig, DE)

Traffic is one of the most important complex systems of our modern world, with several levels of complexity reaching from individual actions of a driver, over local phenomena like density fluctuations and traffic jams, regional and temporal traffic patterns, all the way up to long-range traffic development and regulation. In recent years, tremendous progress has been made in understanding the dynamics of traffic flow and traffic congestion; however, a number of serious obstacles still prevent efficient coordination and regulation of traffic. Three of the most serious impediments have been the incompleteness of input data, the computational intractability of forecasting the behavior of real-life traffic consisting of huge numbers of vehicles, and the lack of local communication (and thus: cooperation) between drivers.

With the advances of modern communication technologies, it has become possible to keep track of virtually all data of driving vehicles. Understanding traffic as a complex system that is based on local interaction suggests studying distributed computing approaches for controlling traffic phenomena. Finally, wireless ad-hoc networks allow real-time interaction and data exchange between adjacent vehicles. In this talk I describe how these tools can be used to improve the flow of congested traffic. Simulations suggest that this may allow saving about 40% of energy for cars in a traffic jam.

Algorithms for Movement Patterns

Joachim Gudmundsson (NICTA - Sydney, AU)

Recent technological advances of location-aware devices and mobile phone networks have made it possible to easily get access to large amounts of tracking data. As a result analysing the data is becoming harder and it will require algorithms and software to detect interesting patterns. We give a brief overview of existing algorithms for detecting movement patterns. The first results were presented in the PhD thesis by Imfeld in 2000 and then extended and enhanced in several consecutive articles (Laube and Imfeld 2002 and 2003, Laube, van Kreveld and Imfeld 2004, Laube, Imfeld and Weibel 2005). These articles formalised the field of movement patterns and made them accessible for the computational geometry community which has since then produced a large amount of literature in the research area, including algorithms to detect flock patterns, popular places and leadership patterns. Recently the community has seen a move toward more fundamental problems such as trajectory simplification, median trajectory and trajectory clustering.

Scale and Granularity in Movement Analysis

Patrick Laube (Universität Zürich, CH)

The scope of this presentation is twofold. The first part shall provide an equal foundation on scale and granularity – key concepts in geography – to the interdisciplinary audience and provide a state of the art on scale and granularity particularly in movement analysis. Relevant work from the GIScience literature, behavioral ecology, and mathematical biology are discussed. The first part concludes with the observation that there is little evidence of cross-scale analysis in the literature, despite its importance as attested by research in all three areas. The second part discusses a specific cross-scale sensitivity study conducted on a data set tracking cows in captivity. The study demonstrates that deriving oft used movement parameters such as speed, turning angle or sinuosity is sensitive to the chosen temporal sampling scale, uncertainty in the measurement of fixes and the approach taken to segmentation.

Keywords: Scale, Granularity, Uncertainty, Sampling Rate, Movement

Report from MPA'10 workshop

Patrick Laube (Universität Zürich, CH)

Recent developments in movement pattern analysis reflect the broad interest in this field. Just as broad seems to be the methodological spectrum scientists develop to investigate movement patterns. Although the plethora of application fields, in fact, calls for a wide spectrum of methodologies, it is difficult to find a common strategy in the community that would help in sharing results, exchanging methods as well as heading towards what would be an established theory on movement pattern analysis. It was the goal of the first workshop on movement pattern analysis, held in conjunction with GIScience 2010 in Zurich, 14 September 2010, to contribute to such a common view on methods of movement pattern analysis. The workshop attracted more than 40 scientists, both with application and theory backgrounds.

Concrete datasets were moved into the centre of this workshop. The idea was to arrive at an answer to the question of what makes a useful benchmark dataset for movement pattern analysis. Such benchmark datasets could significantly help in the long-term goal to work on a common theory of movement pattern analysis, since benchmark datasets provide means to compare different methods.

The attendees in general agreed that the lack of methods comparability is a problem, and that it could be tackled with benchmarks. Such benchmark data should rather be real observation data, not simulated data, semantically annotated and allow multi-scale analysis.

Keywords: Benchmarking, Movement analysis

See also:
http://ceur-ws.org/Vol-652

Mobility Analytics in Geospaces

Harvey J. Miller (University of Utah, US)

Time geography is a long-standing conceptual framework that focuses on how individuals generate mobility by trading time for space in movement to access activities. It also describes the spatial and temporal constraints that restrict individuals from activity participation, as well as the activity coordination that generate collective spatio-temporal dynamics. In recent years, researchers have developed analytical and computation methods based on the time geographic framework. This lecture describes two core time geographic concepts: the space-time path (a measure of actual mobility) and the space-time prism (a measure of potential mobility). The lecture also describes analytical measures of the path and prism in three types of geospaces: planar space (continuous space with a uniform maximum velocity), network space (discontinuous space with varying velocities) and fields (continuous space with varying velocities). The lecture concludes by identifying open questions associated with mobility analytics in geospaces, and the use of these measures in knowledge discovery and delivery.

Vulnerability of Paths

Jörg-R. Sack (Carleton University, CAN)

We study problems relating to security of paths in networks. In particular, this includes establishing that the following problem is NP-hard. In a network G, find K paths from a source to a destination node such that the number of shared links (used by more than one paths) is a minimum. Furthermore, we give an approximation algorithm for that problem and establish inapproximability to within a factor of $2^{log^{1-\epsilon}n}$ unless $NP \subset DTIME(n^{polylogn})$. We also implemented a heuristic that performs well in practice.

Keywords: Network security

Joint work of: A. Maheshwari, M. T. Omran, H. Zarrabi-Zadeh, and J.-R. Sack

Incremental Acquisition of Information from GPS-Tracks

Monika Sester (Leibniz Universität Hannover, DE)

From massively available GPS-tracks environmental information can be automatically derived, like geometry of roads, but also attributes such as number of lanes or traffic restrictions. The basic idea is to describe a process which incrementally improves existing road data with incoming new information in terms of GPS traces. In this way we consider the GPS traces as measurements which represent a "digitization" of the true road. Although the accuracy of the traces

is not too high, due to the high number of measurements an improvement of the quality of the road information can be achieved. The presentation shows a method for integrating GPS traces and an existing road map towards a more accurate, up-to-data and detailed road map. First, cross-sections of the existing road are created by a sequence of perpendicular profiles and get the road's candidate sampling traces which intersect with the profile. Then we match the potential traces with the road and finally estimate the new road centerline from its corresponding traces. In addition to the geometry of roads we also mine attribute information from GPS traces, such as number of lanes. Furthermore, we explore the benefit of an incremental acquisition by a temporal analysis of the data.

Median Trajectories

Rodrigo I. Silveira (UPC - Barcelona Tech, ES)

We investigate the concept of a median among a set of trajectories. We establish criteria that a "median trajectory" should meet, and present two different methods to construct a median for a set of input trajectories. The first method is very simple, while the second method is more complicated and uses homotopy with respect to sufficiently large faces in the arrangement formed by the trajectories. We give algorithms for both methods, analyze the worst-case running time, and show that under certain assumptions both methods can be implemented efficiently. We empirically compare the output of both methods on randomly generated trajectories, and analyze whether the two methods yield medians that are according to our intuition. Our results suggest that the second method, using homotopy, performs considerably better.

Browsing Storm Tracks

Aidan Slingsby (City University - London, GB)

We worked with some climate scientists at the Centre for Atmospheric Science at Reading Universit to build a interactive tool to visually browse thousands of simulated storm tracks over several decades. These tracks may give a better representation of the variation in storm tracks than the (relatively short) historical record. The original requirement was to produce a means to create animated video clips of the stormTtracks evolving through time. These were required for presentations to insurance industry representatives.

Our solution was a tool that enabled visual browsing for identifying examples which could be exported. Spatial and temporal clustering and extra-tropical storm transition were examples of video clips that were extracted for use in such presentations. However, the climate scientists found that the ability to visually browse their dataset is useful for validating their model and discussing aspects of

the modelling to peers. This enabled them to explore their data in ways that were not previously possible with their existing tools. We are now engaged with ongoing work to collaboratively design means for them to address specific research questions. This was the winning entry of the Discovery Exhibition competition at IEEE visWeek.

See also:
http://www.discoveryexhibition.org/pmwiki.php/Entries/Slingsby2010

Motion Models and Kalman Filters

Jack Snoeyink (University of North Carolina - Chapel Hill, US)

I give a brief overview of Kalman filters which are commonly used in applications that must derive position, velocity, and other motion parameters from noisy observations of position. My colleague, Greg Welch, has an excellent page for more details on Kalman filters: `http://www.cs.unc.edu/~welch/kalman`. We need to know something about them to properly interpret trajectories from GPS data loggers, and to give consistent estimates of trajectory parameters.

The idea is the following: If you have a model of state changes (with noise of known covariance) and observations from state (with noise of known covariance) then you can predict the next observation, and use the residual to correct the estimate of state and of covariance. For example, a simple difference equation relates position+velocity from one time step to the next, so even though only position (up to GPS error) is directly observable, the filter maintains estimates of position and velocity.

If the process is linear and the noise is Gaussian, then the Kalman filter is provably optimal. A large body of research provides variants that work well when these conditions are relaxed.

Keywords: Motion model, Kalman filter, Velocity estimates

Full Paper:
http://www.cs.unc.edu/∼welch/kalman

Geospatial Activities as Context Information

Sabine Timpf (University of Augsburg - Augsburg, DE)

Spatio-temporal patterns usually are found when analyzing data on moving point objects. However, their meaning often is unclear and the analyst is unsure weather the patterns that were found will be meaningful to the domain specialist. While the domain specialist knows about the context of the dataset and has some potential patterns in mind, by contrast the analyst does not have that advantage. In my talk I argue that patterns only get created because of some purposeful behavior, i.e. because the moving point objects move because

they carry out some activity or task. Patterns without purposeful behavior can be considered noise, although some non-purposeful behavior such as "loafing" might be interesting in itself. So how can we distinguish purposeful behavior, i.e. activities versus meaningless patterns? When enriching a pattern of moving point objects with additional information, we can distinguish between different activities: So the pattern "moving in a straight line" is considered "flying" (e.g., seegulls), whereas moving in a straight line with an upwards movement is called "soaring", and moving in a straight line over a longer period of time (at a higher level of abstraction, i.e. a smaller sampling frequency) can be termed migrating. Oftentimes, we see patterns in behavior that are not ascribable to a single activity, but come about because of a combination of activities or behaviors. These are even harder to detect. In my talk I suggest to describe activities as context in a formal way, i.e. determine the qualitative shape of the activity, the scale compared to the size of the subject, the expected pattern, and potential meaningful combinations of activities and their effect on patterns. These "activity templates" could then be matched against patterns found in the data. The questions this approach raises are manifold: How can activities and their spatial patterns be described formally, how can influencing parameters be introduced into the descriptions, how can the interaction of activities be described in terms of their patterns or their parameters? In addition, the question may be raise if the description of parameterized activities is sufficient to describe the context of meaningful moving point objects.

Keywords: Pattern Analysis, Moving Objects

Trajectories from Bluetooth-Tracking

Mathias Versichele (Universiteit Gent, BE)

Bluetooth-tracking was presented as a novel tracking methodology. It consists out of tracking mobile phones and other Bluetooth-enabled devices and using them as a proxy for studying movement behavior of the device carriers. Using this technology entrails both advantages and disadvantages in comparison with traditional methodologies. Indeed, it offers a relatively cheap and easy way of sampling (very) large populations of moving objects in various environments (outdoor and/or indoor) without the need for cooperation of the studied subjects. The sampled trajectories are however much coarser than for example GPS-tracks and, although it is not in any way illegal, the technology also causes some privacy-concerns. The methodology was illustrated by showing some preliminary results from a tracking study carried out during a cultural mass event in Belgium.

An Introduction to the Research on Bird Movement at UvA

Emiel Van Loon (University of Amsterdam, NL)

Many of the big questions in ecological research can only be answered if we are able to sample animal movement at a much higher rate and with much more flexibility than what we have been using until now. At UvA, a versatile GPS sensor has been developed which enables us to collect such samples, especially for bird movement. The possibilities of this sensor are shown, as well as the first research results.

Keywords: GPS tracking

Joint work of: Bouten, Willem; Shamoun-Baranes, Judy; Camphuysen, Kees; van Loon, Emiel

Model based analysis of movement data

Emiel Van Loon (University of Amsterdam, NL)

One of the big questions in migration research is: why does it occur, can we explain it only in the perspective of evolution, or are there also contemporary (physiological, demographic etc.) reasons why migration is beneficial for the survival of a species (Gauthreaux, 1982). The key aspect in bird migration is the energy balance of individuals, as it is quite closely related to survival and breeding success (Berthold, 2001). And for long distance migrants, winds determine to a large extent the energy cost of migration (Bowlin et al. 2010). Our two questions, contributing to the 'big question' associated with bird migration, are therefore: a) does wind exert an important influence on the energy balance of long distance migrants, relative to other potential influences; b) can we describe and explain the response of long distance migrants to wind?

Keywords: Bird migration, GPS-tags, Wind compensation, Individual based model

Activity Patterns in Public Space

Stefan van der Spek (TU Delft, NL)

Traditional Urban Analysis techniques and methods to collect information about (actual) movement are limited: these methods don't show 'the whole story' and are not reliable. Using GPS it is possible to collect accurate and valid spatio-temporal data (trajectories) on pedestrians and households. This data includes, next to background information, routes, flows, destination, duration of trips,

mode of transportation, etc. for one person during one or more days. Individual and collective (aggregated) data can be used to analyze and evaluate the city and initiate developments for improvement.

TU Delft / Urbanism carried out several experiments/pilots and field research project to collect spatio-temporal data. Two types of collections are distinguished:

1. People walking, e.g. in city centers, at events, etc.
2. Households (taking into account all movement)

Keywords: Urban design, GPS tracking, Spatio-temporal data, Visualisation

See also:
http://www.bk.tudelft.nl/urbanismontrack

See also: 'Urbanism on Track: Application of Tracking Technologies in Urbanism', S.C. van der Spek and J. van Schaick (eds), Reseach Series in Urbanism (RiUS), Volume 1, IOS Press, Delft/Amsterdam, 2008

Gull behaviour classification

David M. Mountain (City University - London, GB)

A classification of gull behaviour, with classes defined by Emiel van Loon. The classification is not intended to be complete, or non overlapping.

This classification emerged from the discussion of the "Gull Data" working group.

The group discussed that this classification is a combination of two distinct concepts:

– gull behaviour, as traditionally recorded in time budget analysis. For
– example, nesting, eating, foraging. It is unclear which behaviours have
– distinct spatial patterns; spatial patterns, for example directional flight.

It might be appropriate to split this single classification into two, one representing gull behaviour, and one spatial patterns, and try to identify linkages between behaviour and patterns.

Keywords: Gull data behaviour pattern

Overview of related work

Marc van Kreveld (Utrecht University, NL)

In the area of moving object analysis, I have worked mostly on the algorithmic aspects. I have developed algorithms for finding motion patterns, determining subtrajectory similarity, segmenting a trajectory, etc.

Keywords: Trajectories, algorithms

Geovisual Analytics for Trajectories - 3D kernel density

Urska Demsar (National University of Ireland, IE)

Modern positioning and identification technologies enable tracking of almost any type of moving object. A remarkable amount of new trajectory data is thus available for the analysis of various phenomena. In cartography, a typical way to visualise and explore such data is to use a space-time cube, where trajectories are shown as 3D polylines through space and time. With increasingly large movement datasets becoming available, this type of display quickly becomes cluttered and unclear. To solve this problem, we introduce the concept of 3D space-time density of trajectories. The space-time density is a generalisation of standard 2D kernel density around 2D point data into 3D density around 3D polyline data (i.e. trajectories). Visualisation can be used in any kind of situation where many trajectories are present, but might be of particular interest in cases where movement is in relatively unconstrained space.