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COMMUNITY ACTIVITY: WORKSHOP REPORT

Report on the first workshop on Movement Pattern Analysis (MPA10)

Summary: This paper reports on the first Workshop on Movement Pattern Analysis, held as a pre-GIScience 2010 workshop in September 2010 in Zurich, Switzerland. The report outlines the scientific motivation for the event, summarizes its main contributions and outcomes, discusses the implications of the gathering, and indicates directions for the road ahead.

1 Introduction

The first workshop on Movement Pattern Analysis, MPA10 for short, was held in Zurich, Switzerland, September 14th and was co-located with the sixth International Conference on Geographic Information Science (GIScience 2010). The workshop brought together researchers mainly coming from geographic information science, but also from computer science, engineering and other fields having an interest in the analysis of moving objects. Most attendees are investigating movement patterns with regard to their specific fields, including transportation, animal ecology, and spatiotemporal knowledge representation. The workshop attracted more than 40 participants, making it the most popular pre-GIScience workshop in 2010. Its organizers were Patrick Laube (University of Zurich), Björn Gottfried (University of Bremen), Alexander Klippel (Pennsylvania State University), Nico Van de Weghe (Ghent University), and Roland Billen (University of Liège). The workshop proceedings can be found at http://ceur-ws.org/Vol-652 [3].

In the following, we first outline the motivation for this workshop. We summarize three invited presentations on theoretical aspects of movement pattern analysis, provide a commented list of discussed application problems, and an overview of the outcomes of the break-out group discussions. Finally, the main contributions and implications of the workshop are highlighted.

2 Benchmarking in movement pattern analysis

The organizers of this workshop recognized the lack of a common theory of movement pattern analysis, although much research has been carried out in this field during the last decade. A lot of interest exists in the analysis of moving objects both at the theoretical and application-driven level [5]. The driving force of the application-driven research, mainly in the geographic field, has been the great advancements made at the technological level regarding tracking technologies. In parallel, a lot of research has been completed in the field of knowledge representation, in particular to represent and reason about movement patterns [1, 2, 8]. The multidisciplinary interest in movement patterns is particularly challenging in that the spectrum of methodologies used by scientists to investigate movement patterns is wide. Although the plethora of application fields 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 and comparing methods, and heading towards what would be a general and consistent theory on movement pattern analysis. The main goal of this workshop was therefore to advance such a common theory on methods of movement pattern analysis.

As a first step towards such a general theory, the workshop aimed at improving the comparability of methods through the discussion of benchmarking for movement pattern analysis. Merriam-Webster defines *benchmark* as a "standardized problem or test that serves as a basis for evaluation or comparison (as of computer system performance)" [7]. In essence methods become comparable when tested against standardized benchmark problems. This idea is not new, but has proved to be useful in various methodological research fields, such as for testing ice sheet models [4] or evaluating visual analytics tools [9]. In information visualization, for instance, the popular yearly series of Visual Analytics Science and Technology (VAST) challenges invites scientists to test their latest methodological developments against a given task around a given data set in a competitive setting. Such systematic benchmarking initiatives "facilitate the comparison of different techniques and encourage researchers to work on challenging problems" [9, p. 120], and thereby advance the theoretical underpinning of the respective science field.

Before benchmarking will play a similar role in movement pattern analysis, suitable standardized tasks and data sets need to be found and sufficiently characterized. Generally, movement pattern analysis endeavors to explicitly capture the space-time structure in data in order to meaningfully analyze moving objects. Repositories of reference movement data sets are rare, partly due to privacy, security, or copyright restrictions. Also, for data sets that are available in the public domain metadata is often scarce, as semantically annotating movement data is expensive and hence mostly copyrighted. Nevertheless, the spatial information science community, with the diverse data acquisition techniques available today, is assumed to be in the position to have among its members significant amounts of movement data that could be potentially developed into reference data sets. It is, however, not entirely clear what defines a useful benchmark data set, for evaluating and comparing methodologies.

Therefore, the central question of the workshop was "what makes a useful benchmark data set for movement pattern analysis?" Such benchmark data sets could significantly help in the long-term goal to work on a common theory of movement pattern analysis.

3 The MPA10 workshop

It was an explicit goal of the workshop organizers not to hold yet another mini-conference based on research talks, but rather engage attendees in hands-on working groups and facilitate cross-disciplinary discussion on the potential of benchmarking for movement pattern analysis. For that reason, concrete data sets and specific application problems were moved into the center of the workshop. Instead of calling for research papers, the call for participation explicitly asked for the presentation of application problems and associated data sets, which the authors thought would be suited for benchmarking in movement pattern analysis. Submissions should especially highlight why their data or problem could be a benchmark for movement pattern analysis.

The structure of the workshop was threefold: first, three invited talks gave a critical overview of progress and challenges in areas relevant to movement pattern analysis. In a second session all application problems were introduced in a series of mini presentations. In the most important third section of the workshop, four break-out groups discussed the idea of benchmarking in movement pattern analysis in the light of the beforehand presented application problems.

3.1 Keynote talks

Harvey Miller (University of Utah, USA) discussed *Mobility in geospaces: What can we say analytically (so far)?* Miller focused on substantial progress in the analytics surrounding the core concepts of mobility science: the space-time path and prism, representing actual and potential mobility, respectively. His presentation reviewed analytical representations of the path and prism in three different geospaces—planar, network, and velocity fields. The talk also highlighted methods for estimating error and uncertainty propagation from imperfect measurement of their parameters.

Kathleen Stewart (University of Iowa, USA) asked *Patterns of moving objects: Why so interesting?* In her talk she discussed progress in research relating to the semantics associated with patterns of moving objects. The talk highlighted how time in particular serves as an important foundation for extracting many different kinds of moving object semantics. Stewart discussed different temporal data models and how the choice of models exposes different moving object semantics.

Christophe Claramunt (Naval Academy Research Institute, Brest, France) gave his keynote, entitled *Moving objects at sea: Trends and challenges*. Claramunt deliberately took a different perspective and considered moving objects not on land but at sea. He gave a survey of current techniques, research advances, and issues of the specific domains around objects at sea. The talk surveyed current maritime information systems and navigation-aided systems and some of the research projects developed at the Naval Academy Research Institute in France, while emphasizing some of the research challenges still open.

3.2 Application problems

Presenters were asked to discuss the suitability of their data for benchmarking in movement pattern analysis. The topics of interest included the semantics of the observed processes, metadata and data structure, and observable patterns and processes. Eight out of twenty submissions were selected for inclusion in the workshop:

- A. Millonig, G. Maierbrugger—*Identifying unusual pedestrian movement behavior in public transport infrastructures*
- M. Versichele, M. Delafontaine, T. Neutens, N. Van de Weghe—*Potential and implications of Bluetooth proximity-based tracking in moving object research*
- Z. Wood, A. Galton—*Identifying characteristics of collective motion from GPS running data*
- Y. Yuan, M. Raubal—*Spatiotemporal knowledge discovery from georeferenced mobile phone data*
- I. Downes, L.Guibas—*Network structure discovery for vehicular ad-hoc networks*
- G. Gidófalvi, E. Saqib—*From trajectories of moving objects to route-based traffic prediction and management*
- K. Rehrl, S. Leitinger, S. Krampe, R. Stumptner—*An approach to semantic processing of GPS traces*
- S.C. Ahearn, J.L.D. Smith, A. Simchareon, S. Simchareon, J. Garcia—*Modeling the relationships between patterns of movement of Panthera tigris and its behavioral states*

Millonig and Maierbrugger presented movement data from a study on stress-inducing factors in transport infrastructures. The strength of their data is its rich semantic annotation. Millonig and Maierbrugger used "shadowing," where researchers track and follow the test subjects and annotate the test subjects' individual trajectories and related activities on a map. Versichele et al. tracked massive numbers of individuals using a Bluetooth proximity-based tracking procedure at a mass event (Ghent Festivities 2010). Even though such coarse proximity-based data can't compete with GPS tracking in terms of temporal and spatial granularity, its sheer volume bears potential for benchmarking sequence patterns in mass events.

Wood and Galton proposed the use of GPS tracks of runners for the analysis of collective motion. The collection of such data is straightforward, flexible, of limited privacy concern, and offers very fine temporal granularities needed for multi-scale analysis. Yuan and Raubal presented typical georeferenced mobile phone data, featuring call logs of one million people for a time span of 9 days tracked in Harbin City, China. Mobile phone data analysis is a subfield in movement analysis rapidly gaining momentum, but privacy concerns remain an issue (see also Versichele et al.).

Downes and Guibas proposed the use of vehicular trace data from agent-based models (ABM) for studying communication in vehicular ad-hoc networks. Although hardly representative of real-word examples, ABM allows for the creation of controllable experiments, a key element for benchmarking. Gidófalvi and Saqib proposed GPS readings of 1500 taxis and 400 trucks traveling on the streets of Stockholm for benchmarking the performance and accuracy of systems for traffic prediction and management tasks. Such fleet data is typically rich and accessible, but the taxi and logistics context is very specific and potentially limits required broad benchmarking.

Rehrl et al. suggested the use of vehicle GPS traces and a web-based software (Location Intelligence Suite, LIS) for categorizing transport mode, motion behavior and course change patterns. The universal nature of mode of transport or basic movement patterns ("stand still," "positive acceleration") are especially well suited for benchmarking. Finally, Ahearn et al. presented animal GPS tracking data for studying animal-animal and animal-environment interactions. Tracking data from behavioral ecology is very promising for benchmarking in movement analysis as such tracks are typically annotated with direct observations of behaviors (e.g., female hunting patterns with and without cubs).

The authors presented their application problems in five minute slots and provided portraits summarizing the characteristics of their problems as a basis for the following break-out sessions.

3.3 Break-out sessions

The hands-on part of the workshop was conducted in four interdisciplinary break-out groups, each discussing two of the above application problems. These discussions were additionally guided by a set of four questions that the organizers had selected after a poll amongst the MPA10 committee members. In the following the questions are presented along with summaries of the group discussions.

1. What characteristics/properties should a benchmark data set have? The delegates agreed on the utmost importance of metadata describing the semantics of the observed process. Knowledge about uncertainty in the data as well as different sampling granularities was considered important. An ontology of environments, movement patterns, and moving entities was considered critical. From a statistical perspective the question of sample versus population was raised.

2. What data is better suited for benchmarking in movement pattern analysis: Real data or synthetic data? A clear preference for real observation data over simulation data was observed. However, it was acknowledged that acquiring sufficient semantic information remains difficult with real observation data. Controlled movement experiments were named as a suitable compromise.

3. How can benchmark data sets be organized (technically, conceptually)? Whereas no technological limits were identified for providing repositories of reference movement data sets, copyright restrictions and privacy concerns were identified as open issues. Again, ontologies were discussed here (see 1.)

4. Do you think the establishment of benchmark problems/data sets will lead to progress in movement pattern analysis at all? The delegates agreed that so far little cross-method comparison is possible and that the use of benchmark data/problems is a suitable way forward to increase comparability amongst movement pattern analysis methods. Once again, the need for an ontology of patterns and/or of tasks was discussed. Given the diversity of involved application domains and resulting data sets/problems, the delegates concluded that not one single benchmark data set should be put forward, but the community should rather aim for a set of application domain specific benchmark data sets.

4 Conclusions and outlook

During the workshop it became clear that the idea of benchmark data sets and benchmark tests were not very well known by many participants. Some argued that their main interest was solving their own rather specific application problems. Also, they saw privacy and copyright issues and the need to compile and provide benchmark data in a way that they would be well received by the community. Others emphasized the advantages of benchmark tests and stressed that different methodologies would become comparable with such test data sets. Benchmark data would help to link different approaches developing in parallel in different communities. It was furthermore suggested to learn from other fields where benchmarking has helped advancing the theory, for example robotics, where well-defined goals guide where the community is heading.

As a result, it was recognized that a wide range of benchmark tests would be necessary, each of which would analyze or stand for a more-or-less specific category of problems. For this purpose, such data sets would have to capture different aspects: different sampling rates, clean versus noisy data, complete versus incomplete data, semantically annotated data, and different target groups, such as specific animals, humans, and single or mixed transportation modes.

The unconventional format of the workshop proved to be a suitable means for facilitating a cross-disciplinary discussion about benchmarking in movement pattern analysis. The deliberate forgoing of conventional paper presentations allowed for intense discussions in the break-out groups. Further guiding of the discussion with a set of questions and application problem portraits successfully focused the discussions on the aimed for deliverables. MPA10 provided a forum for face-to-face interaction, required to align the diverse movement analysis community along a common theoretical basis.

In future papers we will hopefully see more methodological comparison and a convergence of movement analysis methods towards a set of standard tasks. Organized community activities, such as a movement data analysis challenge similar to VAST in visual analytics, could further support this alignment.

Acknowledgments

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