Trajectory and Mobility Based Services: A Research Agenda

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Abstract. In light of the definition of- and research agendas for Location Based Services (LBS), this paper first defines Trajectory- and Mobility Based Services (TBS and MBS) which place the trajectory-, mobility- or mobility need of an individual user or a population of users in the center and then presents the problem characteristics and challenges in TBS and MBS for two class of applications: (i) *resource-aware trajectory / mobility services* and (ii) *trajectory based resource infrastructure and operations optimization*. The paper's aim is to 1) implicitly present a work-in-progress research agenda for TBS and MBS, 2) cluster and raise the interests of researchers from different fields and 3) start the process of alternative or complementary characterizations and the process of discovery of new challenges and opportunities in TBS and MBS.

Keywords. Trajectory and Mobility Based Services, resource-aware trajectories, trajectory based infrastructure and operations optimization

1. Introduction

Driven by advances in communication and information technology, such as the increasing availability and accuracy of GPS technology and the miniaturization of wireless communication devices, Location Based Services (LBS) started to gain popularity in the early 2000s and quickly became an integral part of our daily life.

LBS can be defined as computer applications (especially mobile computing applications) that deliver information tailored to the *location* and *context* of the device and the user (Raper et al. 2007; Huang et al. 2018). While it is difficult to determine the number of LBS in existence, by analyzing the location permissions of mobile applications one can conclude that, as of 2014

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Q3, potentially one quarter of the 1 million mobile applications on Google Play Store were LBS (Olmstead and Atkinson 2015). The prominence of LBS is also marked by the growing research activity around LBS: 2019 marks the year of the 15th International Conference on Location Based Services and the publication of the issues of 13th volume of the Journal of Location Base Services.

In contrast to LBS, in this paper Trajectory Based Services (TBS) are defined as services that provide utility to the mobile user tailed to the user's movement *trajectory*. As the movement trajectory of the user describes the mobility of the user, the definition of TBS is extended to Mobility Based Services (MBS) that include services that provide utility to the user tailored to the *mobility* and *mobility needs* of the user. The subtle differences between LBS, TBS and MBS will become more pronounced through the example applications and challenges that the research agenda below outlines.

The utility of trajectory data: Motivated by the promise of smart cities (including their smart transportation systems and services) and the increasingly available, cloud-based, easy-to-use, big data processing frameworks that allow computations to scale, to utilize and monetize these data assets, commercial companies have become increasingly open to share parts of their trajectory data in an anonymized version. For example, Didi Chuxing ("DiDi"), the world's leading mobile transportation platform, has recently announced the worldwide expansion of its GAIA initiative to facilitate data-driven research in transportation (Green Car Congress 2018). Through this initiative, scientists can apply for access to the anonymized GPS trajectory data to explore solutions to traffic challenges including time of arrival estimation, route planning, supply and demand forecasting, transport capacity and congestion management etc. Similarly, while providing a lot less detailed information, primarily due to its high coverage of the population's mobility, in recent years, cellular network data is also increasingly shared by mobile network operators to aid sustainable development (De Montjoye et al. 2014). For example, cellular network data is increasingly used to extract trips, travel modes, travel demand, routes and cumulative flows for travel behavior modelling (Breyer at al. 2018).

Aims: The aim of this paper is three fold. First, in light of this growing availability- and expected utility of trajectory data, the aim of this paper is to present the problem characteristics and challenges in TBS and MBS based on example applications. Second, through this categorical presentation the paper hopes to cluster and raise the interests of researchers from different fields including LBS, geoinformatics, computer science (primarily data management, data mining, and big data processing), transport science (primarily logistics). Finally, through the categorical presentation and engagement of the research communities the paper hopes to start the process of alternative or complementary characterizations and the process of discovery of new challenges and opportunities in TBS and MBS.

Limitations: The herein described research agenda is a personal view of the author that has been formed by working in the field of trajectory and mobility data mining for over a decade and being active in the intersection of the LBS-, spatio-temporal data management- and transport science research communities. For these reasons the research agenda is not comprehensive and should be viewed as work-in-progress.

2. Related Work

Raper at al. (2007) provide a young and somewhat narrower- and Huang et al. (2018) provide and a more mature and wider research agenda for LBS. These research agendas first identify trends in the field and then describe and hierarchically group issues in- and key research challenges of LBS. To some extent, both of these works mention "tracking history", "navigation history" (i.e., trajectories) and "movement patterns" (i.e., mobility patterns) and even state these as possible bases for services (i.e., context), due to the comprehensive nature of these works, trajectories, mobility needs and patterns and their importance for some applications is not sufficiently emphasized. Other works, describe discipline- or field specific aspects of LBS, e.g., Jensen (2002) describes data modelling, indexing and query processing and optimization aspects of LBS from the field of spatio-temporal / moving object data management. Yet other works, draw connections to related disciplines and their research issues, e.g., Jiang and Yao (2006) do not find substantial fundamental differences and a clear-cut boundary between the research issues of LBS and GIScience and foresee a future where the differences and boundary further fades as "GIS functionalities are embedded in tiny sensors and microprocessors." Finally, while Brilingaite et al. (2004) presents key concept and software that discovers routes of a user along with their usage patterns and makes the accumulated routes available to services (i.e., LBS context), the importance of this context is not emphasized (i.e., generic LBS is assumed). In comparison, the present paper focuses on trajectories, mobility needs and patterns and their importance for TBS and MBS and describe- and identify challenges in- two classes of applications.

3. Trajectory and Mobility Based Services

3.1. Example applications

Resource-aware trajectory / mobility services: For a new set of TBS, mobile users need to acquire or collect resources to accomplish their mobility needs. Some example of services and their resources are as follows: 1) routing services that integrate the dynamic availability and cost of parking at different locations; 2) routing services that integrate the need to maintain the connectivity to a vital resource (e.g., wireless communication to a control tower for remote-driving of autonomous vehicles in emergency situations) throughout the trajectory; 3) routing services for electric vehicles that integrate the need to ensure electric operations under on-board energy storage constraints by charging at electric charging infrastructure components (stations or electric road segments) that have dynamic availability / capacity and costs; and 4) electromobility related services that based on the mobility patterns of a user (including driving style and related energy use) and the availability and cost of charging provide optimal charging strategies for the user.

Trajectory based resource infrastructure and operations optimization: Analogous to the above user-centric TBS, one can also define a set of new operator-centric MBS that try to optimized the location and availability of resources for large group of TBS users primarily based on the trajectories or mobility needs of the users. Some example of services, their resources and optimization objective are as follows: 1) services that under a budget constraint find the resource-infrastructure that can guarantee access to- and availability of the resources (e.g., carking / connectivity / electric energy) for most or all of the users given their mobility patterns or needs and 2) services that given a resource-infrastructure with dynamic capacity-constraints (e.g., available parking, network bandwidth, energy supply) find access control policies or pricing schemes that optimize the resource operations (e.g., utilize the resources or balance the demand for the resources) given the users' mobility patterns or needs. The distinction between mobility patterns and needs is crucial. Mobility patterns (e.g., routes) are observed mobility behavior of users, which can rapidly change based on how MBS optimize the resource-infrastructure and its operations and based on what TBS the users use to access the resource-infrastructure. In comparison, mobility needs represent the users' underlying need to reach a destination, which, in comparison, are expected to remain relatively stable.

3.2. Challenging problem characteristics

The ***problem characteristics*** that are associated with these services are rooted in the spatial and spatio-temporal relationship between the trajectories-, mobility patterns and needs of a single or group of users and the location and temporally changing availability and cost of the resources. In particular, in most cases, *the utility of a resource is highly dependent on its spatial relation with the movement trajectory of the user*, e.g., an electrified road segment has just as little benefit to a user with an electric vehicle that has a full battery or have enough battery to reach its final destination where cheap stationary charging is available as the benefit is of cheap parking space at a location that is far away from the destination of the users. Moreover, because users may need to acquire several resources to accomplish their mobility needs but cannot infinitely accumulate resources due to limited storage capacity (i.e., battery), *the utility of a resource is highly dependent on the location and amount of resources that were previously acquired and consumed during the movement trajectory* of the user. Finally, because the resource-infrastructure has to cater for the mobility needs of multiple users that are in competition with one another, *the utility of- or demand for resources is defined by the complex topological relationships between trajectories*. Dealing with these problem characteristics is ***challenging*** and require combinatorial optimization methods that can "untangle the complex topological relationships between a large number of trajectories" and efficiently estimate the utility- and availability of a resource individually and as part of an infrastructure / network.

To better exemplify the challenges and problem characteristics, consider the task of finding the optimal placement / selection of electric road segments to meet the energy demand of battery electric vehicles. In particular, consider the case of heavy freight trucks that cannot be equipped with large enough batteries to cover their energy demand and should be charged while moving in order to reduce their idling time and spread the energy demand on the electric grid (Gidofalvi and Yang 2019, Gidofalvi and Yang 2020). For a fixed electric road infrastructure budget N, the optimization problem can be stated as "Select N unit-length segments in the road network for electrification so that the transport work of the vehicles (vehicle-km traveled) in electric mode (ERS or battery) is maximal." To evaluate a candidate solution requires the ability to efficiently simulate the vehicles' battery state at each point of their trajectory according to an energy storage-, consumption- and charging model. For realistic problem sizes at national / international scale, this requires the processing of billions of trip trajectories, e.g., a fleet of 20,000 trucks produce TBs of GPS trajectories annually. To improve a candidate solution requires the calculation of the *electrification utility* of a segment, which can be defined as the additional transport work that can be carried out in electric mode due to the electrification of the segment. Due to the battery capacity limits of the vehicles, the electrification utility of segments is not independent of one another. In particular, the dependence between the electrification utility of two segments is influenced by the battery states of vehicle whose trajectories directly or indirectly (through other electrified segments) connect the two segments. To find the optimal solution, given a road network with M segments, requires the evaluation of an exponential number of (M choose N) candidate solutions.

4. Conclusion

This work-in-progress paper advocated the importance of trajectories- and mobility needs and patterns for TBS and MBS and described- and identified challenges in- two new classes of applications (*resource-aware trajectory / mobility services* and *trajectory based resource infrastructure and operations optimization*), which was aimed to trigger the interests and future engagement of research communities and the evolution of the research agenda that will hopefully lead to new opportunities and challenges.

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