Data-driven Approaches for Smart Parking

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Abstract. Finding a parking space is a key problem in urban scenarios, often due to the lack of actual parking availability information for drivers. Modern vehicles, able to identify free parking spaces using standard on-board sensors, have been proven to be effective probes to measure parking availability. Nevertheless, spatio-temporal datasets resulting from probe vehicles pose significant challenges to the machine learning and data mining communities, due to volume, noise, and heterogeneous spatio-temporal coverage. In this paper we summarize some of the approaches we proposed to extract new knowledge from this data, with the final goal to reduce the parking search time. First, we present a spatio-temporal analysis of the suitability of taxi movements for parking crowd-sensing. Second, we describe machine learning approaches to automatically generate maps of parking spots and to predict parking availability. Finally, we discuss some open issues for the ML/KDD community.

1 Introduction

Very often, in urban scenarios, drivers have to roam at the end of their trips on the search for a parking space, worsening the overall traffic and wasting time and fuel [5]. *Smart Parking* refers to Information and Communication Technology solutions meant to improve parking search by providing information about parking locations and their actual or estimated availability. While it is rather trivial to gather parking availability information for parking facilities, it becomes tricky for on-street parking, where there are mainly two sensing strategies: stationary or mobile collection. The former relies on sensors embedded in the road infrastructure, continuously measuring whether stalls are free or occupied. However, it is too expensive to cover a wider city area with those sensors. The latter mainly exploits participatory or opportunistic crowd-sensing solutions from mobile apps or probe vehicles [6], that can occasionally detect free parking spaces. Mobile sensors are pretty cheap to deploy in comparison to the stationary ones but the quality and the spatio-temporal resolution of the obtainable data streams is lower, posing many challenges for the automatic extraction of useful knowledge.

In this paper, we give an overview of some approaches we used to exploit mobile sensor data for Smart Parking scenarios. In particular, in Section 2 we summarize a study showing that a small fleet of taxis equipped with standard sensors can provide parking availability information comparable to a large number of stationary sensors [1, 2]. Then, in Section 3, we show two actual Smart Parking use cases attainable with machine learning techniques on probe vehicle data: (I) identification of parking legality of small road segments [4], and (II) prediction of parking availability [3]. Finally, issues still to be faced by the ML/KDD Community are discussed in Section 4.

2 Mining taxi GPS trajectories to assess quality of crowd-sensed parking data

Probe vehicles are a promising solution to scan parking availability, since series sensors, like side-scanning ultrasonic sensors or windshield-mounted cameras, can be effectively used to determine free parking spaces. Mathur et al. [6] were the first to conduct a preliminary evaluation on the potentiality of taxis as probe vehicles, using a real-world dataset of GPS trajectories in San Francisco, USA. Some simplifications in their assumptions motivated us to investigate more deeply the topic, answering the questions whether the spatio-temporal distribution of a fleet of taxis is suitable for parking crowd-sensing and how many taxis are needed [1, 2]. For that, we processed and combined parking availability sensor data from more than 400 road segments with over 3000 parking spaces from the SFpark project[3] in San Francisco, with trajectories of about 500 taxis[4] in the same area, with more than 11 million GPS points over three weeks.

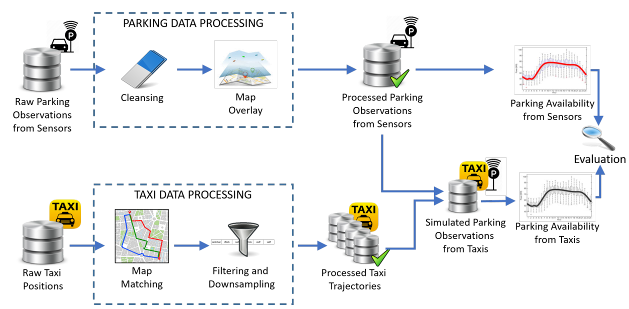

Fig. 1. The evaluation pipeline for combining parking data with taxi trajectories [2].

An overview of the processing steps to compare the spatio-temporal characteristics of parking and taxi movements is illustrated in Figure 1. Both datasets needed to be matched to the same street network, taken from *OpenStreetMap*. Also some non-trivial cleansing and filtering were required to have comparable datasets. The taxi trajectories were then aggregated to compute a typical weekly behavior per road segment. Assuming that taxis would have observed parking

[3] http://sfpark.org/
[4] http://crawdad.org/epfl/mobility/20090224/

availability each time they traversed a road segment, we calculated a dataset of parking observations achievable by taxis by downsampling the stationary sensor data according to the timestamps of taxi visits per road segment. The actual parking availability was then estimated from the last observation of the taxis.

In a direct comparison of the parking availability information from mobile and stationary sensors, we found that the regular trips of 300 taxis (about 20 % of all licensed taxis in San Francisco at that time) were sufficient to cover the SFpark project area in San Francisco with a maximal deviation of ± 1 parking spaces with respect to stationary sensors in more than 85 % of the cases. This result is remarkable since the taxi coverage revealed strong variability with the time of day, but can be explained by the fact that parking turnover showed a similar time dependence. The time until the next taxi visit was less than 30 minutes for about 60 % of all road segments and time instants. Therefore, we concluded that the spatio-temporal movements of taxis are well suited to crowd-sense parking availability.

3 Machine learning approaches for on-street parking information

In this section we describe two use cases for Smart Parking we can derive on top of the data stream coming from probe vehicles.

Learning parking legality from locations of parked vehicles The location of parking lanes and the legality of parking in a specific spot is the first relevant information for drivers looking for a free space. Parking might be not allowed in front of e.g. garage exits, or even for a full road if the road is narrow. Thus, drivers should focus their search on areas with many parking spaces. As the location of parking spaces is often unknown to non-local drivers and on-street parking maps do not exist in many cities, we developed a crowd-sensing approach to learn the parking legality from the location of parked vehicles at different time instants [4]. For every small road segment unit, several spatial and temporal features were extracted and a binary decision was performed to distinguish legal from illegal parking spots. Multiple classifiers were evaluated on parking availability data, collected on 9 trips with a probe vehicle on more than five kilometers of potential parking spaces. Results show that the random forest classifier achieved the best results. However, also k-means clustering plus a simple classification heuristic performed nearly as good as the first one, without the need for costly training data.

Predicting parking availability Based on the parking availability information, a prediction is useful to provide a suggestion to drivers approaching their destination. There exist some data-driven prediction approaches in the literature [5], mostly formulated as a regression problem and only considering input data at a constant frequency. Since most of the drivers are rather interested whether or not there is at least one free parking space in a road segment and what is the corresponding probability, we reformulated the problem as a binary classification task that also is robust for irregular sampling [3]. As features, we used the last observations of the sensors in a road segment as well as the aggregated observations up to a certain distance in the surroundings, the parking capacity, and the time of day and day of week. We evaluated the approach using a random forest classifier with data from the SFpark project. Results show that the binary parking availability of a road segment can be predicted with a F1-score of about 75 % for 30 minutes ahead.

4 Conclusions and Open Issues

Crowd-sensing vehicles, measuring the on-street parking availability during their regular trips, represent a new source for large amounts of parking data that promise to mitigate parking search problems. For example, maps of parking spaces can be automatically generated, parking availability predicted, and search recommendations given to frustrated drivers. However, due to the highly irregular spatio-temporal coverage of the generated data, also new research challenges arise for these applications. As the highly irregular sampling needs to be considered, standard time series approaches cannot be applied to predict parking availability. Also, as parking is a very dynamic phenomenon, extracting the trends in parking occupancy from the fluctuating data remains a challenge. Another open question is how learned models can be transferred to other cities. Finally, it is also very relevant to investigate whether additional approaches are necessary for irregular events like concerts or sport matches.

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