ABSTRACT
The prevalence of positioning technologies has fostered massive trajectory data. Data points from trajectories indicate the visiting of moving objects to locations, which provide an opportunity to understand the locations comprehensively. Many existing works rely on stay points to analyze locations. However, they are ad-hoc solutions to tackle specific problems, and it is time-consuming and tedious to develop each application. In this paper, we propose a universal Stay point-based Location analysis platform, i.e., SALON, with the characteristics of universality, efficiency and flexibility. It can retrieve stay points using flexible conditions, associate stay points with locations, extract comprehensive location profiles and visualize the analysis results to users. Based on the combination of these functions, we demonstrate three different location analysis scenarios, i.e., illegal location discovery, popular location ranking, location temporal analysis to show its characteristics.

CCS CONCEPTS
• Information systems → Spatial-temporal systems.

KEYWORDS
Spatio-temporal Data Mining; Location Analysis; Interactive Exploration

ACM Reference Format:

1 INTRODUCTION
With the wide adoption of GPS-enabled devices, massive trajectory data has been generated every day, which represents different mobility behaviors of moving objects. Among them, an individual’s staying behavior provides us an opportunity to understand the interaction between moving objects and locations. The staying behavior is usually reflected by the stay point in his/her trajectory, which represents a moving object stays in a geographical region for a while. With those stay points, many location analysis-based applications can be facilitated, e.g., risky region discovery [1], POI recommendation [12], and urban planning [2].

However, to support different applications, one has to design problem-specific solutions. Apart from that, even for similar tasks, processing steps and parameters should be tweaked, and visualization techniques should be employed to produce good results due to different data distributions. Therefore, developing those applications is extremely time-consuming and tedious. In fact, many processing steps of those works are shared in common.

In this paper, we propose a universal Stay point-based Location analysis platform (SALON) 1, which tends to provide a convenient and efficient approach to obtain insights into location analysis results through interactive exploration for product managers, government regulators, researchers, etc. We take full consideration of the properties of stay points and locations, and integrate the common processing steps for location analysis tasks. As shown in Figure 1, the platform takes raw GPS logs and geographical entities such as POI, road network as input, summarises six processes covering data pre-processing, management, interaction and visualization.

The advantages of our platform are summarized as follows: 1) Universality. The platform supports multiple analysis methods to tackle various applications. 2) Efficiency. The platform uses JUST [5] as database and builds spatial indexes for spatial data. Users can obtain analysis results in a short time. 3) Flexibility. The platform supports interactive retrieval and analysis. Users can customize parameters in these functions and explore the analysis results by different parameters.

In order to show the advantages of our platform, we demonstrate three scenarios: 1) Illegal location discovery, 2) Popular location

Figure 1: System overview
which builds the foundations of data interaction. This section is divided into two steps. (1) trajectory pre-processing, which transforms trajectory data to stay points with semantic information; (2) spatial index building, which manages stay points and geographical entities for efficient join and query.

3 OFFLINE PROCESSING

In this section, we present data pre-processing and management, which builds the foundations of data interaction. This section is divided into two steps. (1) trajectory pre-processing, which transforms trajectory data to stay points with semantic information; (2) spatial index building, which manages stay points and geographical entities for efficient join and query.

3.1 Trajectory Pre-processing

Trajectory pre-processing is important, as the data noise and outliers in raw data affect the accuracy and performance of later applications. Moreover, we can also enhance the stay points with semantic meanings extracted from time, location, and the spatio-temporal patterns of the moving objects, which makes the stay points retrieval more flexible. The platform covers the following sub-tasks in the trajectory pre-processing [6–8]:

Noise Filtering. Due to sensor noise and other factors, such as receiving poor positioning signals in urban canyons, trajectories are never perfectly accurate. We employ a heuristic-based outlier detection algorithm [10] to remove noise GPS points.

Stay Point Detection. This task extracts a subset of consecutive GPS points as a stay point which represents that the moving object has stayed for a while, such as waiting for passengers, loading goods. We adopt a clustering-based algorithm [4] to extract stay points. Respectively, we obtain the centroid \((lon, lat)\), the mid-time \(t_{mid}\) and the difference between the end time and the start time \(\Delta t\) as a stay point’s attributes from the above subset.

Semantic Enhancement: This task enhances stay points with semantic information which can be indicators to retrieval and analysis. For stay point itself, we consider the district where it is located \((\text{region})\), the day of the week \((\text{semantic}_t)\) when it is generated. For each moving object \((oid)\), we extract its frequent stay locations in different periods, e.g., night or daytime by clustering its stay points. Then for each frequent stay location, we extract its province, city and location type as the moving object’s labels \((\text{oid}_\text{label})\).

Overall, a stay point is characterized as follows:

\[
SP = (oid, \text{oid}_\text{label}, lon, lat, t_{mid}, \Delta t, \text{region}, \{\text{semantic}_t\})
\]

3.2 Spatial Index Building

SALON contains two types of data, respectively, the processed stay points and geographic entities. A geographic entity is a geographic feature, like a restaurant or a road segment. It occupies a position in space and its attributes and geographic location are recorded in the related database. In SALON, we use POIs and road networks as geographic entities to retrieve stay points and analyze location...
auxiliarly. In order to achieve interactive analysis and make the platform efficient, these massive data will be indexed and stored in a spatial database [5–7] for retrieval and data summaries.

4 ONLINE INTERACTION

In this section, we present the online interaction of the location analysis task based on stay points. This section is divided into three steps. 1) Stay Point retrieval, which is used to obtain candidate stay points; 2) Stay Point-Location Association, which focuses on the way to associate stay points with locations. 3) Location Profiling, which summarises the properties of each location and generates statistics and analysis results.

4.1 Stay Point Retrieval

In order to obtain desired stay points and apply them to different applications, we take full account of the properties of stay points and design four main selection dimensions as follows:

Spatial condition, which pays attention to each stay point’s spatial features, such as the region, POIs and road network, e.g., finding stay points that are close (e.g., within 50m) to any restaurant;

Temporal condition, which focuses on a temporal feature of the stay points, e.g., finding stay points on Sundays;

Object condition, which is used to obtain stay points of moving objects with the same label, e.g., finding stay points generated by moving objects whose resident place is a university;

Attribute condition, which focuses on the duration of each stay point, e.g., finding stay points whose duration is more than 30min.

We support a free combination of these types of conditions to flexibly obtain desired stay points.

4.2 Stay Point-Location Association

In some applications, the underlying location is known, such as all gas stations in a city, while in others, the location is unknown, such as an illegal warehouse. Therefore, we devise the following two association methods.

Clustering-based Association. We adopt density-based spatial clustering of applications with noise (DBSCAN) [3] to generate frequently visited locations. The platform supports users to customly input this algorithm’s parameters (minpts and eps) according to different application scenarios.

Category-based Association. The platform contains location data with categories from OpenStreetMap [2] and allows users to select one particular category to analyze. We focus on stay points within these locations regardless of quantity.

4.3 Location Profiling

Location profiling is an essential process of our platform, which helps us understand location better through concrete value and distributions. To meet the universality, we extract static and dynamic features for each location, details as follows:

Static features, which indicate where the location is and what is around the location. There are many kinds of static features. For example, calculating the distribution of road network around a location infers its traffic status in one city. In our platform, we identify the center point of location (longitude and latitude), distribution of POIs within 100m and distribution of road network within 200m as static features, which can well infer the location’s significance and functions.

Dynamic features, which indicate access of moving objects to the location. As we focus on stay points within the location, information about moving objects they visit are natural dynamic features. For example, if a location contains hundreds of taxi stay points, the location can be regarded as a candidate drop-off and pick-up location with high popularity. In our platform, we propose six dynamic features (the number of stay points, the number of moving objects, the frequency of visits, distribution of visit periods, distribution of visit weeks/months/years, distribution of visit duration) to describe the moving objects’ visiting pattern of the location.

5 DEMONSTRATION

As shown in Figure 4, the main page contains four sections. The Data Interaction panel supports four types of stay point retrieval and two types of location analysis for users to obtain desired stay points and apply them to different scenarios. The Data visualization is used to display stay points and locations on the map. The button in the lower-left corner is designed for map switching. The Data statistics panel displays the overall dataset summaries. The Data Distributions panel is used to visualize the spatial-temporal distributions of stay points, including temporal distributions, POI distributions, road network distributions, etc.

![Figure 3: System Viewing Interface.](image-url)
for obtaining candidate illegal locations, as shown in Figure 4(b). Next, we filter these candidate locations to find locations whose number of visits is more than 10 and the number of objects is less than 3, as shown in Figure 4(c). Finally, as shown in Figure 4(d), we show a suspicious illegal location with the highest number of visits. Moreover, this location is indeed an illegal warehouse for chemicals based on the on-field investigation.

Popular Location Ranking can be widely used in taxi management, in which the driver can have full knowledge of popular locations for receiving passengers to avoid wasting time and resources.

5.3 Location Temporal Analysis

We use Geolife [11] data, which contains 5 years of GPS records for 183 moving objects. Due to the long period of the data, we can observe location temporal variation, such as year, month, day. As shown in Figure 6, we give the example of Beijing Happy Valley. This location is from the category-based association and the parameter is theme_park. We find June is the peak month for the location and more visits on Fridays and Saturdays by tracking the moving objects’ visiting time.

Location Temporal Analysis helps us understand a location’s cyclical characteristics and development. It is widely adopted in urban planning.

Figure 5: Ranking of popular locations for taxis.

5.2 Popular Location Ranking

We switch the dataset to T-drive[9], which contains 7 days of GPS records for 10,357 taxis. In this example, we explore where taxis often stay in the evening nearby restaurants. Like the first scenario, We first obtain stay points described above, which satisfy the following criteria: 1) the duration of the stay point is less than 30 minutes, 2) the time of the stay point is within 17:00-21:00 and 3) there exist POIs with the type of restaurant within 50m. Then we use clustering analysis mode. As shown in Figure 5, we display the ranking of popular locations, according to the number of visits and then combine the map to show the top two locations specifically.

Figure 4: Processes of obtaining an illegal location.

Figure 6: Example of location temporal distribution.

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REFERENCES