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Exploring visitor movement patterns in natural recreational areas

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ABSTRACT

GPS technology is widely used to produce detailed data on the movement of people. Analysing massive amounts of GPS data, however, can be cumbersome. We present a novel approach to processing such data to aid interpretation and understanding of the aggregated movement of visitors in natural recreational areas. It involves the combined analysis of two kinds of movement patterns: 'Movement Suspension Patterns' (MSPs) and 'Generalized Sequential Patterns' (GSPs). MSPs denote the suspension of movement when walkers stop at a place, and are used to discover places of interest to visitors. GSPs represent the generalized sequence in which the places are visited, regardless of the trajectory followed, and are used to uncover commonalities in the way that people visit the area. Both patterns were analysed in a geographical context to characterise the aggregated flow of people and provide insights into visitors' preferences and their interactions with the environment. We demonstrate the application of the approach in the Dwingelderveld National Park (The Netherlands).

1. Introduction

Monitoring and analysing the flow of visitors in natural recreational areas is key to understanding visitor behaviour, which in turn is needed for effective management that meets both conservation and recreational requirements (Mckercher & Lau, 2008; Muhar, Arnberger, & Brandenburg, 2002 pp. 1–6). To understand these requirements we need detailed information about area usage and the preferences of different target groups (Chiesura, 2004). Analysing the spatial behaviour of visitors by relating different uses and activities to different places and landscape configurations can provide insights into their preferences and purposes (Golicnik & Ward Thompson, 2010). One of the most important aspects of the spatial behaviour of visitors in recreational areas is their movement inside the area (intra-site flow). Monitoring the movement of people during their visits to a recreational area can help to identify which places they visit most or least, how much time they spend in each place and which kind of attractions different target groups prefer. Knowing those preferences, managers can segment the market and offer more diverse and focused options, adapted to the wishes of specific groups of visitors (Holyoak & Carson, 2009). Monitoring and analysing the movement of visitors and area usage can also provide information about potential crowding and conflicts between different groups (Manning & Valliere, 2001; Ostermann, 2009). The movement behaviour of visitors looking for solitude and relaxation may differ from visitors looking for social activities, such as playing and picnicking, and studying this can help us understand how different groups experience crowding. The study of intra-site flow of visitors can also provide information for conservation management. To assess the carrying capacity in sensitive areas, for example, we must know about the spatial and temporal distribution of visitors.

Traditionally, studies on visitors' use of space in recreational areas have been based on data and information collected from interviews, surveys and direct observation. Researchers have used geographic information systems (GIS) to analyse the spatial properties of these data to understand how the spatial behaviour of visitors is related to different places and landscape configurations (Golicnik & Ward Thompson, 2010). GIS has also been used to study how recreational areas are used by different groups to detect and understand processes of appropriation and exclusion (Ostermann, 2009).

To complement these techniques, location-sensing technologies (e.g. GPS, mobile phones, PDA) are providing an inexpensive and unobtrusive way to collect massive datasets on the location in space and time of people in recreational areas (Nielsen & Hovgesen, 2004; van Schaick & van der Spek, 2008; Shoval & Isaacson, 2009; Taczanowska, Muhar, & Brandenburg, 2008; Xia, Arrowsmith, Jackson, & Cartwright, 2008). To make sense of this new source of

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data, researchers are envisaging new methods and techniques for exploring and analysing vast amounts of positioning data to extract patterns that represent the movement of individuals and groups (Laube, 2009). Recent advances in the field suggest that despite the potential diversity of movement behaviour, people usually follow simple and predictable movement patterns (Gonzalez, Hidalgo, & Barabasi, 2008; Song, Qu, Blumm, & Barabasi, 2010). It is accepted that these patterns may provide information that will help to explain the interactions between moving entities and between those entities and the environment (Batty, De Syllas, & Duxbury, 2003; Bierlaire, Antonini, & Weber, 2007; Gudmundsson, Laube, & Wolle, 2007; Hoogendoorn & Bovy, 2005). Taking into account the diversity of movement patterns reported in the literature, some authors have proposed formalisation and classification systems to provide a systematic framework for ongoing research (Dodge, Weibel, & Lautenschütz, 2008; Wood & Galton, 2009).

Spaccapietra et al. (2008) stated that in order to analyse movement data and detect useful patterns, the representation of the movement of an object must go beyond its raw spatiotemporal positions. In their work, the authors proposed a representation called 'semantic trajectories', in which the trajectory of the object is divided into semantic units called 'stops' and 'moves'. Stops are those segments of the trajectories where the object does not move. Among various methods proposed to implement this representation, Alvares et al. (2007) devised a method for detecting stops called IB-SMoT (Intersection-Based Stops and Moves of Trajectories), which is based on an analysis of the intersections of trajectories with user-defined geographical features for a minimal duration. Rinzivillo et al. (2008) proposed a similar approach, in which the stops are those segments of trajectories where a moving entity remains within a distance threshold for a minimum period of time. Palma, Bogorny, Kuijpers, and Alvares (2008) proposed a method called CB-SMoT (Clustering-Based Stops and Moves of Trajectories), which analyses each trajectory and generates stops when the speed value is lower than a given threshold for a minimal amount of time.

More recently, Bogorny, Heuser, and Alvares (2010) suggested a general framework for modelling trajectory patterns during the conceptual design of a database. The authors provided a conceptual description of the framework, an implementation of IB-SMoT and SB-SMoT, and data-mining algorithms to extract three movement patterns (i.e., frequent patterns, sequential patterns and association rules) for semantic trajectories. They also provided examples of how to instantiate the model for different applications by parameterising the spatial and temporal dimensions. Other researchers have proposed methods for analysing aggregated movement data to learn more about the spatial behaviour of visitors. For example, Shoval (2010) proposed using a raster-based representation that divides the area of study into a regular grid of cells, and counting the number of GPS observations in each cell of the grid. Finally, some approaches focus on the aggregation of trajectories to improve the visual exploratory analysis of movement data (Andrienko & Andrienko, 2008; Demšar & Virrantaus, 2010; Scheepens, Willems, van de Wetering, & van Wijk, 2011).

A common feature of these approaches is that the conceptualisation of movement patterns requires a parameterisation of spatial and temporal dimensions, which makes the results highly dependent on the values assigned to those parameters. For example, in order to define a stop, the user must provide values for the minimum time, the minimum speed or the minimum distance to be used to determine whether an individual object has stopped, with the risk of overestimating or underestimating the number of stops. Similarly, to detect sequential patterns, the user must set the intervals for aggregating the temporal data in predefined periods (e.g., morning, afternoon, weekend). In the case of spatially aggregated data in raster-based representations, the size of the cell has a considerable effect on the summary statistics. The parameterisation of these values is not trivial and may be highly sensitive to the inherent GPS inaccuracy and to the spatial and temporal resolution of the observations (Palma et al., 2008). Moreover, the selection of parameters is based on a priori knowledge of the dataset, and therefore may be not suitable for an exploratory approach.

In the present work, we propose a novel approach to explore the properties of the collective movement of visitors in recreational natural areas based on GPS tracking data. We define collective movement to be the aggregated properties of the movement of many people in a defined space and time, not the movement of specific groups of people moving together (i.e., collective movement rather than movement of collectives). Our approach relies on different methods of detecting movement patterns that represent the properties of collective movement. In this contribution, we focus on two kinds of movement patterns – Movement Suspension Patterns (MSPs) and Generalized Sequential Patterns (GSPs) – and demonstrate how they can be used to explore the collective movement of visitors in natural recreational areas.

The next section introduces the proposed approach and details the techniques used for the analysis. Section 3 details how the approach was implemented to analyse the flow of visitors in a national park in the Netherlands. Section 4 presents the results of the analysis and Section 5 discusses the most important findings. In the concluding section we briefly review the proposed approach and identify its current limitations and possible solutions.

2. The proposed approach

We want to represent the flow of visitors in a recreational area, defined as the aggregated movement of people visiting different places in a generalized sequence, regardless of the route followed by each individual (i.e. visitors may follow different routes, but a flow exist if the places are visited in a similar order). To represent this flow, we need to uncover spatial and temporal structures describing the visited places and how they are related in space and time. In other words, this flow is a quantitative and qualitative description of the aggregated spatial behaviour of the visitors. It can be graphically represented on a map by arrows between places (Tobler, 2003) and expanded using a space–time cube representation (Hägerstrand, 1970; Kwan, 2004), which we adapted to represent the sequential order in the *Z*-axis. This visual representation shows the general structure of the flow at the global level, as well as the local level of movement, the single elements of the flow representing the relations between the places. It aids the analysis of the way in which people use the area and interact with different geographical features.

We propose an exploratory approach to analysing the flow of visitors in natural areas using GPS data. The proposed approach has three aims: a) to determine the main places visited by the people in a recreational area by detecting Movement Suspension Patterns (MSPs); b) to establish the sequence in which each individual visited those places; and c) to detect commonalities in those sequences by extracting Generalized Sequential Patterns (GSPs).

Movement Suspension Patterns (Orellana & Wachowicz, 2011) denote the suspension of movement associated with places where people stop. MSPs are therefore spatial structures and are used to discover the places of interest to visitors. As MSPs are determined by the spatial-statistical properties of the whole dataset, no spatial or temporal thresholds are required. Generalized Sequential Patterns (Agrawal & Srikant, 1995) describe the sequence in which the places are visited, regardless of the trajectory followed. The term 'generalized' implies a relative order and not an absolute