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Understanding temporal pattern of human activities using Temporal Areas of Interest

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ABSTRACT

Although researchers have realised the importance of time for decades in geography and relevant disciplines, they more or less ignore how our understanding can be greatly enriched through the lens of time. One outcome of this ignorance is that there are a limited number of concepts and methods to analyse the temporal pattern of human activities. In this paper, we try to understand the temporal pattern of activities by simultaneously examining the start and end time of activities, rather than from a conventional view, which usually understands a temporal pattern of activities as a profile of an attribute (e.g. the number of activities) on the time axis. To achieve this, we propose a new concept, Temporal Areas of Interest (TAI), defined as the area on a two-dimensional plane using the start and end time as the X and Y axes, where activity points are densely distributed and therefore attracts people's attention/interest. We also propose a general methodological framework for identifying TAIs. The concept and framework are applied using a week's metro smart card data in Shanghai. Results show both the basic rhythm of human activities and reveal some facts that are unexpected or ignored before, such as the large existence of overtime work or similar activities on weekday evenings and weekends. We think that the proposed method provides an alternative way to understand the temporal pattern of activities and a relatively new perspective in evaluating human activity patterns and the urban functions across the city.

1. Introduction

Human activities not only exist in a spatial context, but also in a temporal context (Yu, 2006). To enrich our understanding of human activities, it is important to analyse their temporal pattern, which involves the examination of various aspects of time use, such as duration, daily rhythm, and so on. Although researchers have realised the importance of time for decades in the field of geography and relevant disciplines (e.g. urban studies and transport), they still tend to put most of research efforts on spatial analysis, and more or less ignore how our understanding can be greatly enriched through the lens of time (Kwan, 2013). One outcome of this fact is that a big family of concepts and methods have been developed to understand the spatial pattern of activities, while much less concepts and methods to understand the temporal pattern.

On the other hand, the insufficient research on the temporal pattern of activities also rests with the lack of detailed temporal information in conventional data. In recent years, the development of information and communication technology rapidly increases the availability of urban data. Smart card data, as one type of these emerging urban data, contain detailed start and end time information of activities with a fine temporal granularity, and have provided a great opportunity to understand the temporal pattern of activities (Pelletier, Trépanier, & Morency, 2011; Zhong, Manley, Müller Arisona, Batty, & Schmitt, 2015).

In this paper, we try to understand the temporal pattern of activities by simultaneously examining the start and end time of activities. From the perspective of visualisation, the temporal pattern of activities can be understood as the distribution of activity points in a two-dimensional plane using the start and end time as the X and Y axes. To further develop this type of temporal pattern analysis, first, we propose the concept of Temporal Areas of Interest (TAIs), defined and visualised as the area that attracts people's attention/interest in the start-end time plane. Second, we propose a general methodological framework for the identification of TAIs using the combination of DB-SCAN and convex hull methods. Finally, we apply the proposed concept and framework using a week's metro smart card data in Shanghai and discuss the findings.

The paper is organised as follows. Following this introduction, we present a brief review of relevant works (Section 2). We then provide

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Table 1
A space-time analytical framework.

Categories	Subcategories	Exemplar data
Type I (or Type S^+T^+): Space-time analysis with tight space-time integration		1. GPS-tracked data about people, animal, and vehicle etc. 2. Household travel survey data
Type II: Space-time analysis with loose space-time integration	Type S^+T: Spatial analysis at different temporal stamps Type ST^+: Temporal analysis at different spatial stamps	The observations (e.g. land use coverage, sales, and traffic counts) of a number of spatial units (e.g. land parcels, shops, and stations) over time (e.g. over years, months, and days)

our explanations on some basic concepts and methods in Section 3. Section 4 presents the methodological framework for TAIs identification, study area, and data. Section 5 presents the findings from our Shanghai case study. We end with a brief conclusion and discussion in Section 6.

2. Literature review

2.1. Space-time analysis of human activities

Although being widely used across various disciplines, space-time analysis has no standard definition (An et al., 2015). Here space-time analysis is defined from a broad view: it is the concepts and methods used to describe, visualise, explain, and predict the representation of various objects and phenomena in space and time. It can be further divided into two types. Type I uses data explicitly with both spatial and temporal stamps, as well as models with tight space-time integration. Although geographers tend to concentrate on space, which is understandable given the emphasis of the discipline, generally speaking, space and time can be regarded as being equally important in Type I. Therefore, we also name Type I as Type S^+T^+, which means priorities (+) are given to both space (S) and time (T). Type II uses data explicitly with both spatial and temporal stamps, but uses models with loose space-time integration. Type II consists of Type S^+T, when researchers focus on the spatial dimension of the corresponding phenomenon, and Type ST^+, when researchers focus on the phenomenon's temporal dimension. In this paper, the proposed TAI-based temporal pattern analysis belongs to Type ST^+. Table 1 shows categories and exemplar data in the space-time analytical framework. In what follows, we provide a literature review from the perspectives of Type S^+T^+ and Type ST^+. Section 2.1.1 mainly aims to differentiate the TAI-based analysis from Type S^+T^+, while Section 2.1.2 aims to figure out the main limitations of the existing studies in Type ST^+. Considering Type S^+T is not directly related to our study, we skip the relevant literature review for brevity.

2.1.1. Type S^+T^+ analysis

Most studies in Type S^+T^+ treat human activities as existing during a time period. From a data perspective, an activity can be regarded as a collection of temporally ordered records each comprised of the triple ⟨ID, S, T⟩, where ID is a unique object identifier, S are spatial coordinates, and T are sequential time points (Hornsby & Egenhofer, 2002). The most frequently used data in Type S^+T^+ are GPS-tracked human activities, and human activities retrieved from household travel survey.[1] Time Geography, first proposed by Hägerstraand (1970), might be one of most prominent achievements in Type S^+T^+. It is a powerful framework for studying human activities under various space-time constraints (Chen et al., 2016; Shaw, Yu, & Bombom, 2008). In this framework, activities are visualised in a three-dimensional space, with two spatial axes representing the geographic space and a third orthogonal axis for time (Kwan, 2000). Several concepts have been developed to understand individual's activities in space and time, such as space-time path, which provides an explicit representation for an individual's activities (including the start/end time and locations of an activity, and the sequence of activities), and space-time prism, which delimits what can be physically reached by an individual from specified locations during a given time interval (Miller, 1991, 2005; Yu, 2006). Besides Time Geography, many other methods have been developed to conduct S^+T^+. For example, path similarity indexes have been used to compare individuals' paths (Chen et al., 2011; Kwan, Xiao, & Ding, 2014). Kulldorff (2001) developed a space-time cluster method, the space-time scan test, which can detect local clusters using a space-time moving window that is cylindrically shaped. Demšar and Virrantaus (2010) introduced the concept of 3D space-time density of trajectories to solve the problem of cluttering in the space-time cube. For those interested in more information on Type S^+T^+, we refer readers to An et al. (2015) and Long and Nelson (2013).

We identify four main differences between the proposed TAI-based analysis and Type S^+T^+ research. First, in nature, Type S^+T^+ research focus more on analysing the space-time characteristics by integrating time and space into the quantitative analysis of activities, while the TAI-based analysis pays a particular attention to the temporal characteristics of activities across various places. Second, the pattern in Type S^+T^+ is delineated based on a set of individuals' space-time paths (3D polylines or trajectories in space and time), while the pattern in the TAI-based analysis is delineated based on a set of activities, each is defined as a temporal point using its start and end time. Third, considering that space can be simplified in the TAI-based analysis (i.e., each place is regarded as a point of interest in space, such as a shopping mall or a metro station), the TAI-based analysis does not try to tightly integrate spatial dimension into its analytical methods. Besides, similar to defining an activity using its latitude and longitude in spatial analysis, the TAI-based analysis defines an activity using its start and end time, which makes it possible to 'borrow' methods in spatial analysis to conduct the TAI-based analysis (Zhou, Deng, Kwan, & Yan, 2015). When it comes to the analytical methods in Type S^+T^+, space must be explicitly incorporated into the analytical methods, such as Time Geography, space-time path measurements, and space-time clustering. Finally, Type S^+T^+ adopts a three-dimensional orthogonal coordinate system to visualise the space-time pattern of activities, with time as the third dimension added to a two-dimensional space (Yu, 2006), while the TAI-based analysis visualises the temporal pattern using a two-dimensional temporal plane. It should be noted that, although there exist several differences about the research focus, pattern delineation, analytical methods, and visualisation between the TAI-based analysis and Type S^+T^+, there is no obvious advantages/disadvantages between them which method is preferred greatly depends on the research context.

2.1.2. Type ST^+ analysis

A time series is a collection of observations made sequentially through time (Chatfield, 2016). Time series analysis is defined as the body of statistical methods for analysing time series (Little, 2013). Most of temporal pattern analysis of activities can be regarded as time series analysis. Among them, an activity is usually treated as existing at a time point, which means that the differences between the start and end time

[1] An activity retrieved from household travel survey can be regarded as a collection of two temporally ordered records each comprised of spatiotemporal information at its start and end time.