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Dealing with spatial heterogeneities to discover spatiotemporal event behaviour

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Abstract:

Comprehension of the geographical world and how it works helps us to better interact with it and make more informed and optimal decisions at right time, which ultimately leads to a better quality of life. Quality of life improvement is the final goal of new emerging concepts such as the internet of things and smart cities. These technologies at a very primary structural layer, the perception layer, use networks of sensors and other data acquisition tools to observe spatiotemporal heterogeneities. There are many natural and artificial characteristics in the world that make it complex and heterogeneous. Most of these properties vary in the spatial and temporal dimensions permanently. In this complex context, studying spatiotemporal events would be difficult because of the multiple underlying processes involved in their occurrences. Due to the wide range of applications, spatiotemporal events can be considered in the fields such as biology, seismology, criminology, and ecology. Considering each field, lots of studies have been conducted to recognize factors affecting them. In this way, it is possible to model the event occurrence. This modelling provides a way to control the event, predict it or even use it in early warning systems. It should be noted that although dealing with this heterogeneity and discovery of factors affecting spatiotemporal events are interesting and useful, it is often difficult and time-consuming to identify and examine all the influencing factors, in practice. Even in some cases, this is not possible. In particular, when human behaviours play a vital role in event dynamics. Besides, a proper database that can fully cover the properties and their changes is not accessible most times. Because of the development and maintenance costs of in-situ sensor networks, there are lots of coverage holes, missed values, and inadequate spatial density in such networks. The remote sensing realm has its own difficulties and limitations in data pre-processing, and spatial and temporal data resolutions. Man-made data are very error-prone and they may not be up-to-date, even if they exist. Overall, investigating spatiotemporal phenomena or events happens under the umbrella of uncertainty regarding both data and model aspects. For instance, due to the critical situation during the COVID-19 pandemic, determining factors causing it is of great importance. Understanding the disease spread and its driving factors was very essential in developing policies to prevent and control infections. In this regard, significant efforts were made to investigate the effecting factors on its diffusion. While some research reported no evidence of a relationship between the spread of disease and temperature (Briz-Redón and Serrano-Aroca, 2020), some studies found significant relations between them (Haque and Rahman, 2020). This inconsistency mainly lies in the interdependence, autocorrelation, and heterogeneities of spatiotemporal data types, and also proves that there were other underlying processes driving the outbreak.

To address these issues, instead of studying the factors affecting the considered event, focusing on the spatiotemporal event, its evolution, and its properties in space and time can be advantageous. In this regard, in the current study, a new perspective on the discovery of event dynamics is provided. The history of event dynamics implies all the interdependence and association relations between its affecting factors. Mining this history reveals subregions in which underlying factors behave the same towards the event evolution during the time. In the literature, there are several methods exploring the history of a phenomenon to discover associated subregions, such as SaTScan, Moran's I, and Getis-Ord methods. Nonetheless, these methods are integrated by spatial distances. Whilst, there may be associated subregions that do not locate in their proximity. Moreover, the temporal dimension is not incorporated into spatial ones in these methods. While taking space and time simultaneously into account provides a better way to understand the heterogeneities and dynamics of the physical world. To overcome these shortcomings, in this study, a new approach is investigated to deal with spatiotemporal heterogeneities and the discovery of implicit association relations between different subregions of an area. In addition, the method has the ability to find causality relations between the subregions of an area. In addition, this method has the ability to find causality relations between subregions. To illustrate, if subregion A experiences the event, then subregion B will experience that event. This finding will be very valuable,

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especially in emergency situations where time is very limited and vulnerable areas must be identified quickly to prevent damage or possible breakdowns.

To explain the approach, it is required to define an event. Considering a spatiotemporal phenomenon, an event will occur when its measures exceed a predefined threshold in a spatial unit. Air pollution, crime, accidents, and cases of disease are examples of this event definition. The general flowchart of the proposed method is depicted in Figure 1. As it shows, the proposed approach divides the study area into spatial units. Depending on the considered event, these units can be hypothetical grids or spatial units in which events are reported such as neighborhoods or ZIP Code areas. Spatial distribution and density of events determine whether to choose regular or irregular hypothetical grids. It specifies the size of each grid, too. The method also divides the whole time into timespans. Considering each timespan, it is specified which spatial units emerge as an event. Therefore, a sequence of spatial units experiencing an event in each timespan would be made. In the next step, using a frequent pattern mining method like Apriori or FP-growth all the frequent patterns of event occurrences are determined. The founded frequent patterns indicate homogenous spatial units in the heterogeneous space study area. These units behave the same towards event evolution and dynamics. Next, association rules in spatial units are mined. Discovered association rules reflect causal relationships between spatial units. Hence, regardless of underlying factors contributing to event dynamics, cause-and-effect relations between the different subregions of the study area will be revealed. In this view, more causative centers and more affected spatial units regarding events evolution are recognized. These subregions absorb more attention in the management of event evolution. Since if the event happens there, other areas affected by the causative subregions probably would experience the event. Event emergence in these secondary subregions may activate another cause-and-effect relation in which secondary subregions, affected subregions, appear in the role of primitive subregions, namely causative subregions.

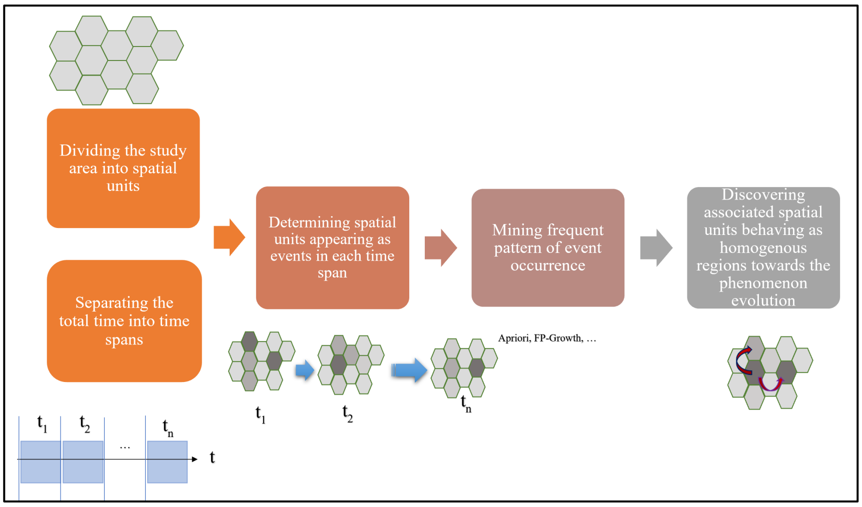

Figure 1. Flowchart of the proposed method

These relations, especially in emergency situations, provide good assets for policymakers and governors to adopt preventive policies and avoid possible damages. In the previous study, this idea was performed on COVID-19 diffusion in New York City at the ZIP Code level by the authors (Habibi et al., 2022). The aim of that study was exploring of disease diffusion and discovery of spatiotemporal association relations. Nevertheless, this idea of dealing with spatial heterogeneity will bring new insights into data science and the analysis of events. It can apply to any other case and achieve exciting and practical results. In the current study, we are exploring the earthquake catalog in Iran using this proposed approach. An earthquake is a natural event that threatens urban areas severely. Iran is one of the most seismically active countries in the world. It has experienced frequent catastrophic earthquakes because of its location in the active collision zone between the Eurasian and Arabian plates. Therefore, investigating interdependence and association relations between its subregions and indicating cause-and-effect relations will be very helpful and necessary in earthquake crisis management.

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