A New Spatiotemporal Pattern Mining to Explore Earthquake Dynamics

Roya Habibi [a,*], Ali Asghar Alesheikh [a]

[a] *Faculty of Geodesy and Geomatics Engineering, K. N. Toosi University of Technology, 19967 15433, Tehran, Iran, rhabibi@mail.kntu.ac.ir, alesheikh@kntu.ac.ir*

* Corresponding author

Keywords: associated seismotectonic regions, association visualization, Iran, association rules, co-location pattern mining

Abstract:

Earthquakes is one of the most complex phenomena in nature. The inaccessible nature of the deep earth and the challenges inherent in observing beneath the Earth's crust make understanding this phenomenon a formidable task. The intricate physics governing earthquakes make their prediction a near-impossible feat in practice. Despite extensive efforts to comprehend the behavior and causes of earthquakes, the full understanding of this phenomenon remains elusive. In this way, mining the pattern of earthquake dynamics provides suitable insights into the geological structure, underlying processes and dynamics of seismic mechanisms. Understanding the complex interplay between seismotectonic regions is crucial for effective earthquake risk assessment and mitigation efforts. A general aspect of seismicity studies involves examining the relationship between earthquake events, specifically whether they are independent or dependent on each other, such as foreshock-mainshock-aftershock sequences and earthquake triggering. However, existing methods for analyzing these relationships face significant challenges that limit their effectiveness. Our study introduces an innovative approach to visualize the implicit network of associated seismotectonic regions, aiming to overcome these challenges and enhance our understanding of seismic activity patterns.

One of the primary challenges in current methods is the limited ability to capture the full extent of interdependencies among seismotectonic regions. Traditional approaches often focus on localized seismic events without considering the broader network of connections that exist between distant regions. By engaging spatial and temporal aspects in a comprehensive analysis, our methodology seeks to reveal hidden correlations and associations that may be overlooked by conventional techniques. Moreover, in spatial autocorrelation context, there exists a distance, termed the *range*, beyond which the correlation between events diminishes and they become uncorrelated. However, there may still be associated regions showing association or similar behavior beyond that range. Our model can determine the associated seismogenic regions in nearby or distant areas, where seismic activities may interact with each other or share underlying mechanisms operating within the same timeframe.

Another challenge lies in the complexity of data interpretation and visualization. Existing methods may struggle to effectively communicate the intricate relationships between seismotectonic regions in a clear and accessible manner. We aim to create intuitive and informative visualizations that enable researchers and stakeholders to easily grasp the underlying patterns and connections within the seismicity network. Our proposed model and visualization approach assist in recognizing areas that are more susceptible to or influential on earthquake occurrences in other areas. These influential regions may act as sources of seismic energy and propagating seismic waves that can trigger or amplify seismic activity in distant locations. In the literature, earthquake triggering studies mainly aim to find susceptible or influential subregions. Whereas these studies focus on a main shock and identifying their dependencies, the proposed model explores the interplays between all the earthquake occurrences in the study area.

The proposed model leverages a spatiotemporal approach to analyse earthquake occurrences. It divides the study area into subregions and defines timespans as arbitrary time intervals. Each subregion experiencing at least one earthquake within a timespan is considered an "event." This method generates a set of events for each timespan, which are then treated as transactions for analysis. Therefore, this approach transforms the spatiotemporal problem into a non-spatiotemporal one, enabling the application of traditional frequent pattern mining techniques. Frequent pattern mining in the realm of spatial context, mainly refers to the co-location or co-occurrence pattern mining. While co-location or co-occurrence pattern mining is common in spatial contexts, it often faces limitations in exploring diverse spatial feature types and incorporating spatiotemporal proximity conditions.

Abstracts of the International Cartographic Association, 7, 53, 2024.
European Cartographic Conference – EuroCarto 2024, 9–11 September 2024, TU Wien, Vienna, Austria.
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Our model focuses on the behavior of a single phenomenon– earthquakes – in spatial containers as single feature type. We also explore a broader area to identify spatiotemporal association regions, revealing areas with co-location of autocorrelated underlying parameters that trigger near simultaneously. This makes the model an extension of traditional co-location pattern mining.

By studying the phenomenon's dynamics, we identify subregions where underlying factors exhibit similar behavior during phenomenon evolution. This can be viewed as finding homogeneous subregions within a complex heterogeneous area (Habibi and Alesheikh, 2023). This perspective was initially introduced in (Habibi et al., 2022) to examine the spatiotemporal diffusion of COVID-19 at the ZIP Code level in New York City. In this previous work, we investigated both the severity and weakness of disease spread, defining events as ZIP Codes experiencing increases or decreases in cases count exceeding a predefined threshold.

Figure 1 represents the results of our model applied on earthquakes in Iran with magnitudes exceeding 3 M_w from January, 1976 to August, 2023. Iran is one of the most seismic active regions of the world. We divided Iran into 198 spatial units. The size of each unit was 1°×1°. This figure shows the discovered network of associated regions in the seasonal time frame, regarding seismic activity. Figure 1.a. illustrates the regions susceptible to earthquake occurrences in other areas, referred to as a susceptibility map. It depicts the spatial units' susceptibility to the seismic activity of the other units. Figure 1.b. displays the influential units where seismic events in these areas probably trigger activities in other units. We call it causality map. The color and size of the circles represent the quantity of these properties. The darker and larger circles indicate the higher quantities.

Figure 1. The map of associated seismogenic regions in Iran in seasonal time frame a) susceptibility map and b) causality map

By addressing these challenges and leveraging innovative approaches to visualize the implicit network of associated seismogenic regions, this study aims to advance our knowledge of earthquake dynamics and facilitate more informed decision-making in earthquake-prone regions. The insights gained from this research have the potential to improve risk assessment strategies, enhance disaster preparedness efforts, and ultimately contribute to the development of more resilient communities in the face of seismic hazards.

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Abstracts of the International Cartographic Association, 7, 53, 2024.
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