

## AN OVERVIEW ON SPACE TIME CUBE VISUALIZATION IN GIS

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**Abstract:** Over the last years, the STC (Space Time Cube) visualization method has been analyzed in many scientific papers in the literature. The term STC comes from cartography, meaning a geographical representation where time is treated as the third dimension. This model was introduced by the Swedish geographer Hägerstrand at the end of the sixties. When datasets involve more than one dimension in addition to time are difficult to visualize. In a geovisualization environment, maps as digital representations are used to emphasize visual thinking about geospatial patterns, relationships, trends. Currently, GIS technology offers dedicated tools that lead to interesting viewing results using this method, the cube and its contents being automatically created from a database.

We reviewed some functions on temporal data, used to view geospatial data sets in different ways. Also in the case study, an earthquake dataset was used, which was represented using the STC method, but also in the form of a temporal slider application.

**Keywords:** Space Time Cube, Time Slider, Hot Spot Analysis, Spatial Cluster

### 1. Introduction

Time can be recorded as an instant (a single point in time) or as a duration (an interval of time with start and end points). [4] The interval between recorded time instants can be regular or irregular. By attaching spatio-temporal reference to measurements it is possible to visualize them in an interactive and dynamic way, but also run spatio-temporal data analysis. Space-time continuum refers that everything we measure on earth can be linked to some space-time (ST) 'location'. [6] Creating a realistic visualization of observed dynamic phenomena the spatial analysis process can be improved, helping to make complex interpretations of analysis results.

Regarding earthquakes dataset, spatio-temporal data can be visualized in a 2D+T space-time cube.

In figure 1 are shown the main elements of ST location.

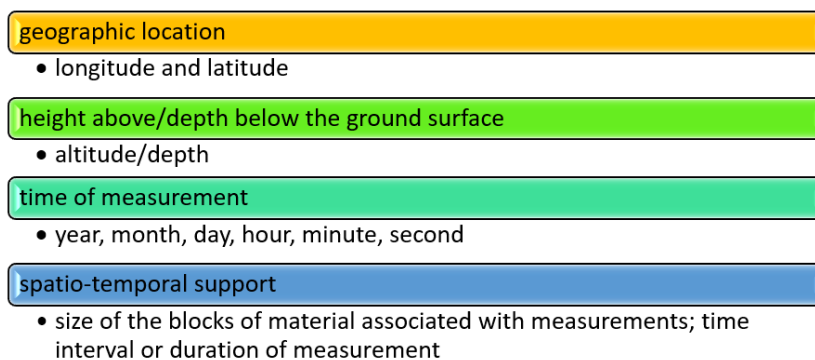


Figure 1 - Space-time location: main elements

As Space Time Cube (STC) philosophy, it needs to be mentioned that time geography sees space and time as inseparable parts, which can visually be well represented by the STC. The cube’s horizontal plane represents space, and the vertical axis represents time. [8]

As previous research efforts and the use of this method, we can highlight the ones in Figure 2 which constitute a relevant synthesis in this respect.

Case study Elements of STC	Geographically related events	Movement of individuals or groups of individuals	Eye-movement data	Landscape changes	Animal behavior analysis
Space-time paths		Hägerstrand (1970) Kraak (2003) Turchenko (2018)	Li, Çöltekin, and Kraak (2010)		Baas (2013)
Space-time path footprint		Kraak (2003)			
Stations	Gatalsky, Andrienko, and Andrienko (2004)	Hägerstrand (1970) Kraak (2003)	Li, Çöltekin, and Kraak (2010)		Baas (2013)
Space-time prisms		Hägerstrand (1970) Kraak (2003)		Bogucka and Jahnke (2017)	
Space-time links				Bogucka and Jahnke (2017)	
STC Cell		Turchenko (2018)		Moylan (2001)	
Base map	Gatalsky, Andrienko, and Andrienko (2004)	Kraak (2003)	Li, Çöltekin, and Kraak (2010)	Bogucka and Jahnke (2017)	Baas (2013)
Ground slices				Bogucka and Jahnke (2017)	
Space-time grid		Turchenko (2018)			Baas (2013)

Figure 2 - Elements of STC discussed within previous research (adapted from [9])

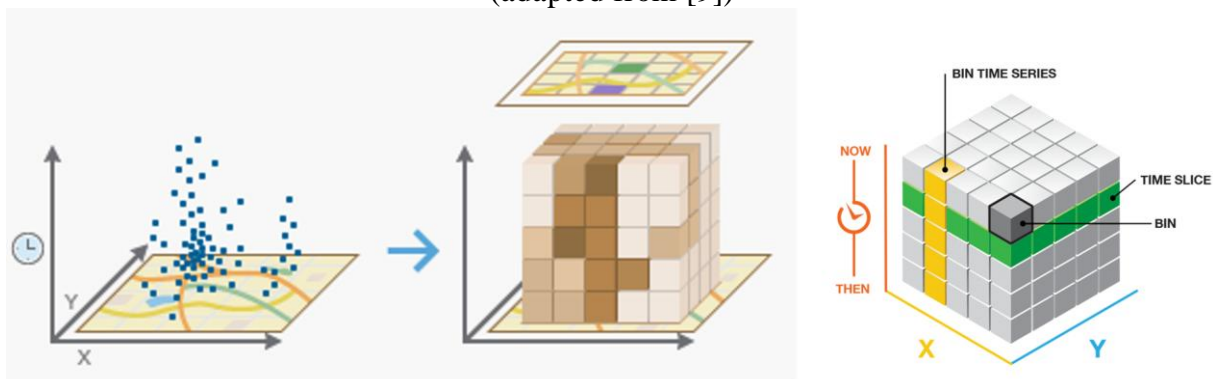


Figure 3 – STC Concept (according to [11])

The data structure is a three-dimensional cube made up of space-time bins with the x and y dimensions representing space and the t dimension representing time. (Figure 3) NetCDF is a file format for storing multidimensional (x, y, z, t) data in an array with x and y representing space and t representing time. The z dimension stores one or more attributes such as temperature, salinity, pressure, magnitude etc. For netCDF feature layers, the layer time is specified using a time dimension or attribute field. For netCDF raster layers, layer time is specified using the time dimension. [4]

The 3D space-time cube can be further explored using the time slider. According to [4], visualizing temporal data is made by the following steps:

- enabling time on a layer and configure the associated time properties (specifying the time attribute or attributes, setting the time extent etc)
- using the time slider to control visualization of the time-enabled layer by playing, pausing, stepping forward or back, setting the time step (the span between time instants that the data is visible) etc.

## 2. Materials and Methods - Study Area and Used Software

We chose for the study earthquakes produced in the Romanian area between 1900 and 2017, as geospatial related events that took place over time. Related data used here were downloaded from the USGS website. The attribute table associated with the layer has been processed to correspond to the definition of the date with the software requirements, and includes information about the magnitude and depth of the earthquakes.

Create STC tool (ArcGIS Pro) was used to aggregate Input Features (point type) into space-time bins and Visualize STC tool for visualizing the result. It is created a netCDF data structure (\*.nc file) by aggregating data into space-time bins. Esri developed a dedicated Add-In for ArcGIS Pro, named Space Time Cube Explorer in the purpose to display the STC by interacting with and exploring the 3D analysis results.

## 3. Hot Spot Analysis - Mathematical Approach

In the ArcGIS Pro Spatial Statistics toolbox are inferential spatial pattern analysis techniques including Spatial Autocorrelation (Global Moran's I), Cluster and Outlier Analysis (Anselin Local Moran's I), and Hot Spot Analysis (Getis-Ord  $G_i^*$ ).

The Hot Spot Analysis tool calculates the Getis-Ord ( $G_i^*$ ) statistic for each feature in a dataset. The resultant z-scores and p-values tell you where features with either high or low values cluster spatially. This tool works by looking at each feature within the context of neighboring features. A feature with a high value is interesting but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature will have a high value and be surrounded by other features with high values as well. The local sum for a feature and its neighbors is compared proportionally to the sum of all features; when the local sum is very different from the expected local sum, and when that difference is too large to be the result of random chance, a statistically significant z-score results (critical values). (according to [11])

$$G_i^* = \frac{\sum_{j=1}^n w_{i,j}x_j - \bar{X} \sum_{j=1}^n w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^n w_{i,j}^2 - \left(\sum_{j=1}^n w_{i,j}\right)^2}{n-1}}} \quad (1), \text{ where } \bar{X} = \frac{\sum_{j=1}^n x_j}{n}, S = \sqrt{\frac{\sum_{j=1}^n x_j^2}{n} - (\bar{X})^2}$$

The Getis-Ord local statistic is given as (1), where  $x_j$  is the attribute value for feature  $j$ ,  $w_{ij}$  is the spatial weight between feature  $i$  and  $j$ ,  $n$  representing the total number of features.  $G_i^*$  statistic is a z-score and no further calculations are required.

As interpretation, the  $G_i^*$  statistic returned for each feature in the dataset is a z-score. For statistically significant positive z-scores, the larger the z-score is, the more intense the

clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot).

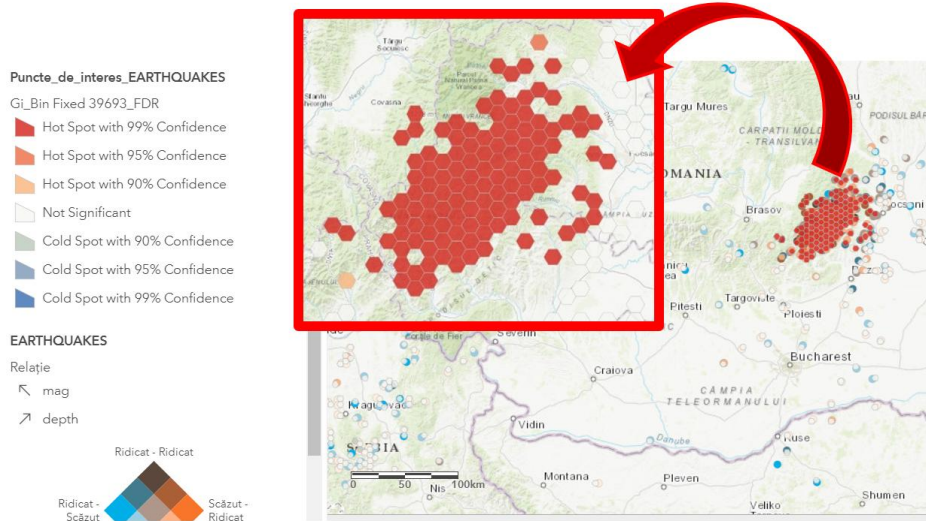


Figure 4 - Hot Spot Analysis (Getis-Ord Gi\*) in the study area (ArcGIS Online)

- p-value is a probability - spatial pattern probability created by some random process. When the p-value is very small, it means it is very unlikely (small probability) that the observed spatial pattern is the result of random processes, so you can reject the null hypothesis.
- z-scores are standard deviations.

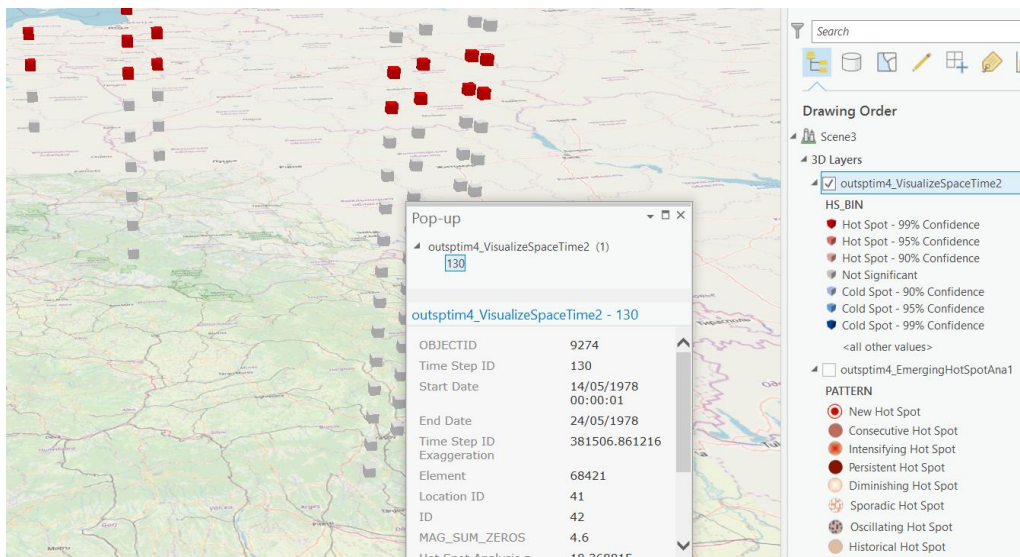


Figure 5 – Earthquakes STC based on Hot Spot Analysis and Attribute Pop-up

#### 4. Analyzing STC

The analysis is based on determining the relationship between a point and its immediate neighborhood, as spatial cluster and spatial outlier.

Local Outlier Analysis geoprocessing function identifies statistically significant clusters and outliers in the context of both space and time. This tool is a space-time implementation of the Anselin Local Moran's I statistic.

The Local Moran's I statistic is given as [11]:

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^n w_{i,j} (x_j - \bar{X}) \quad (2),$$

where  $x_i$  is an attribute for feature  $i$ ,  $\bar{X}$  is the mean for corresponding attribute,  $w_{ij}$  is the spatial weight between feature  $i$  and  $j$ , and  $n$  is the total number of features in the following:

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^n (x_j - \bar{X})^2}{n - 1} \quad (3)$$

The  $z_{I_i}$  is the score for statistics as in the following:

$$z_{I_i} = \frac{I_i - E[I_i]}{\sqrt{V[I_i]}} \quad (4), \text{ where } E[I_i] = -\frac{\sum_{j=1, j \neq i}^n w_{ij}}{n - 1}, \quad V[I_i] = E[I_i^2] - E[I_i]^2$$

Time Series Clustering geoprocessing function is identifying significant partitions in a collection of time series, stored in a STC. The selection is made regarding the similarity of time series characteristics. According to [11], time series have similar values in time or similar behaviors or profiles across time (increase or decrease at the same points in time). The result is a 2D map displaying each location in the cube symbolized by cluster membership and also it can include charts containing information about the representative time series signature for each cluster.

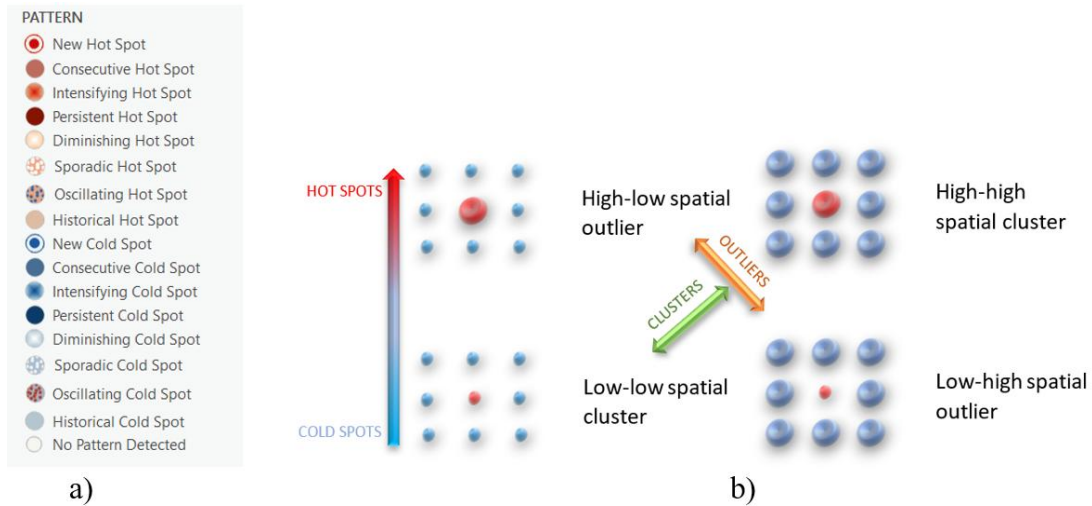


Figure 6 – Classification of Hot Spot vs Cold Spot in ArcGIS Pro (a); Relationship of a location in a Neighborhood Context: Spatial Cluster and Spatial Hot Spot (b) (adapted from [10])

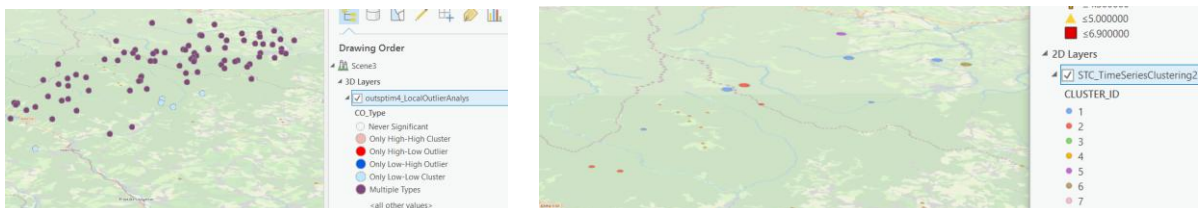


Figure 7 – Local Outliers Analysis and Space Time Clustering

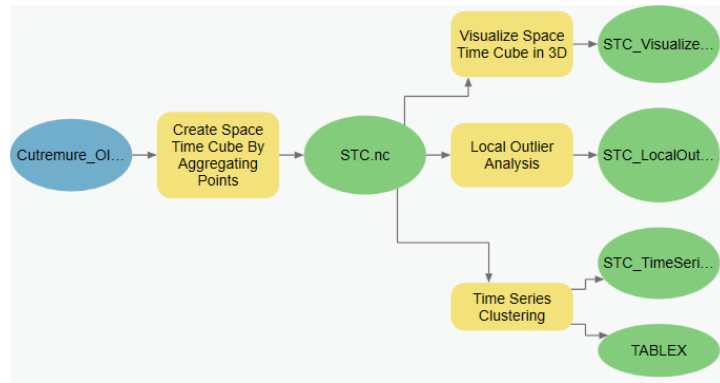


Figure 8 – Functions as a Geoprocessing Model

### 5. Comparison of Space Time Cube with Bivariate Map Visualization

A bivariate map (Figure 9) displays two variables on a single map by combining two different sets of graphic symbols or colors, being an important technique in cartography, as a variation of simple choropleth map that portrays two separate phenomena simultaneously. The main objective of a bivariate map is to accurately and graphically illustrate the relationship between two spatially distributed variables more effectively than a side-by-side comparison of the corresponding univariate maps. (according to [12])

Taking our example of magnitude and depth variables simultaneously, depth could be given a colour scale of white to red, and magnitude from white to blue. Then an area with low magnitude and low depth would be white, high magnitude and low depth would be blue, high magnitude and high depth would be dark brown, while low magnitude and high depth would be red. The human eye can quickly see potential relationships between these variables.

Data classification and graphic representation of the classified data are two important processes involved in constructing a bivariate map. The number of classes should be possible to deal with by the reader. A rectangular legend box is divided into smaller boxes where each box represents a unique relationship of the variables.

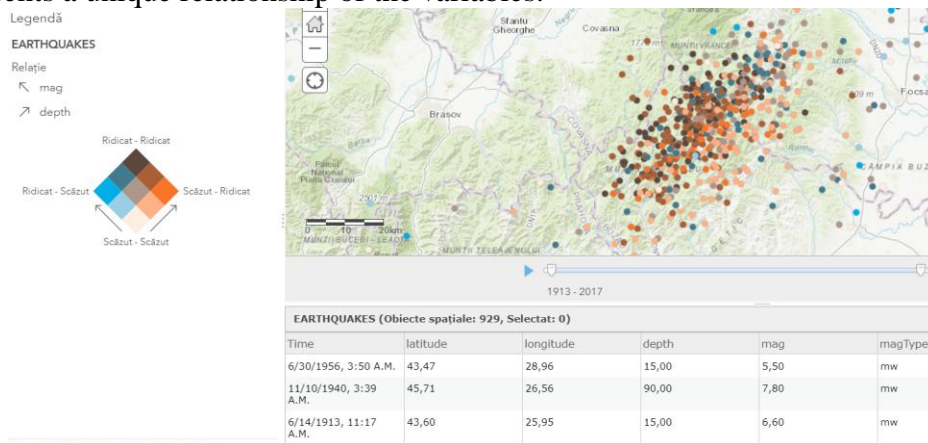


Figure 9 – Bivariate Map (magnitude and depth of earthquakes as variables) with Time Slider

### 6. Conclusion

Time is a relevant dimension in different types of geospatial visualizations and analyses.[3] The temporal aspect highlights when to the where and what of data, emphasizing changes over time.

The 2D map in Figure 9 highlights the earth locations as well as visual informations regarding magnitude and depth. In Figure 10, the same information is represented in the STC, correlated with criteria from Figure 11.

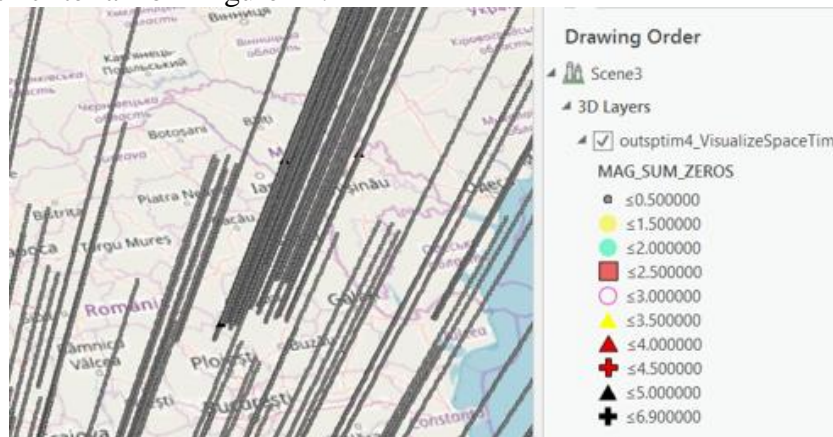


Figure 10 – STC by Earthquakes Magnitude

The 2D map provides a good overview of the earthquakes in the study area, and the points of interest are clearly indicated. However, there is no information of time, except inserted time slider. ([1], [2]) The STC does give immediate insight into the relation between space and time [5], although the cube’s spatial overview might be a little less clear than the map view, but the overall phenomena character is better preserved because locations and time are implicit.

ArcGIS Pro is allowing to exploit the space and time aspects of your data, answering questions like “is there an emerging hot spot?”, or “are there any anomalies?”. [13] It has the added advantage of visualising results in 3D. It is not about predict earthquakes, it is just a perspective on how to review the data in ArcGIS Pro.

Finding a proper resolution for the STC is based on the criteria emphasized in Figure 11.

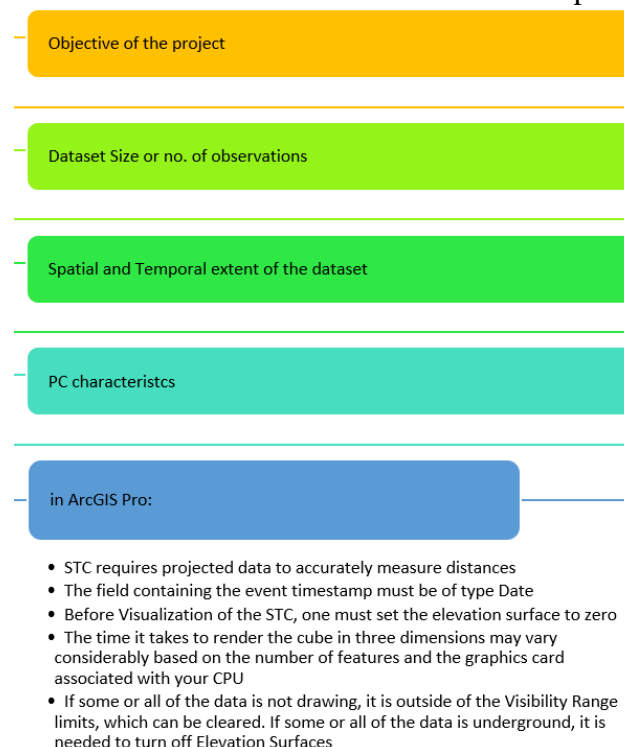


Figure 11 – Criteria for Creating a STC (adapted from [7])

STC is a very useful tool for analyzing data distributions and patterns in the context of both space and time.

In this paper it has been studied viewing and analysis possibilities (based on STC). It is necessary to use larger sets of data in the future work, with significant variations in order to have conclusive results, especially in terms of cluster identification and also it is a need to identify how novice and expert users explore STC data.

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