Spatio-Temporal Visualizer: Online tool to visualize trajectory data using a time-window

Hugo Sequeira

Instituto Superior Técnico
Universidade de Lisboa, Portugal
hugo.sequeira@tecnico.ulisboa.pt
https://github.com/hugocore/spatiotemporal-visualizer

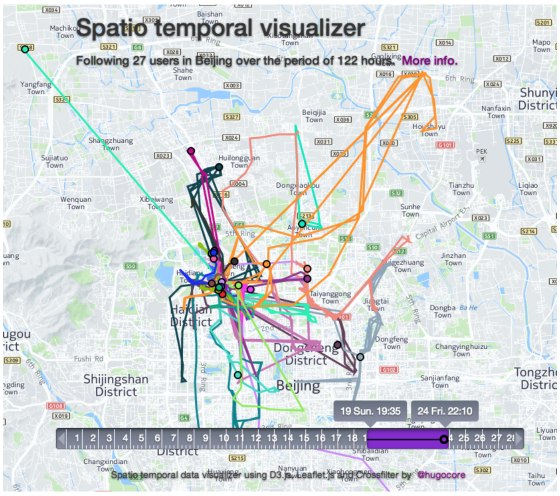

Fig. 1: This work tool to visualize spatio-temporal data.

Abstract. Understanding the dynamics to discover spatio-temporal patterns, relationships and trends is an important task to the solution of many global and local problems. Visualization techniques are crucial tools to provide methods that reveal these patterns and produce new knowledge. Due to its importance, this research area has been very active in the last years. Animated maps with temporal control bars is one of most common visualization techniques. However, no user-friendly online tool, capable of displaying and animating objects has been developed so far. This works, then presents and evaluates a proof-of-concept tool that provides these functionalities to answer spatio-temporal exploratory questions.

Keywords: Geographical Information Systems (GIS), visualization techniques, spatio-temporal data, exploratory analysis, web standards, D3.js

1 Introduction

Exploring temporal geo-referred of moving objects is relevant to people in many application domains. These data, called as spatio-temporal data, are valuable sources of knowledge because they incorporate spatial and temporal aspects of the movement of objects and attributes about the situation in which the movement took place, such as size, shape, temperature, etc. Spatio-temporal data, or more specific, trajectory data are commonly represented as points in the form (id, x, y, t), where *id* is the trajectory identifier and *x, y* represents spatial coordinates at a certain time t [1].

With the increase capacity of monitoring devices, such as GPS devices, the number and size of trajectory data are increasing rapidly. In fact, because trajectory data involves so many aspects it is not easy to perform spatio-temporal analysis [2]. Therefore, it is mandatory to use the right context, filtering and visualization techniques, to efficiently extract knowledge out of raw spatio-temporal data.

Visualization of trajectory data plays an important role to unveil this knowledge, by unveiling patterns, relationships and trends that can be pass unnoticed to the user. Several techniques were developed during the last years to help the visualization and exploration of spatio-temporal data and its attributes [3]. In this work, we group these techniques in three different groups: single, multiple and animated maps. Each one of these techniques has its advantages and disadvantages, but become clear that two-dimensional animated maps was the most suitable to provide better results for a novice user.

According to our research, there are multiple tools to visualize trajectory data on the internet, such as Openlayers, SIMILE, Timemap, and Google Maps [1]. But none of these tools could out-of-the box display trajectory data and provide a temporal bar to manipulate data and navigate through time. Thus, this work goal was to develop a spatio-temporal data visualization tool that could identify patterns, compare and understand individual's behaviors and produce knowledge within a specific period of time, using a very user-friendly user interface, which any kind of user could understand and operate.

The following sections address the existing related work, followed by a overview of this work dataset, description of the methodology and solution implemented, evaluation of the obtained results, and finally, the conclusions from this work and summary of the most important aspects.

2 Related Work

This section makes an overview on the relevant concepts associated with exploratory techniques of spatio-temporal data, addressing its characteristics and approaches to obtain knowledge, and also, the techniques in use today to visualize these data.

2.1 Exploratory techniques and spatio-temporal data analysis

Analyzing spatio-temporal data is an important task which enables past and current patterns to be understood, and furthermore allows for future predictions, based on these spatio-temporal data, to be made. [4]. These patterns are composed of spatio-temporal changes that occur over time. Block [5], classifies these changes in the following categories:

Existential changes such as the appearance or disappearance of an object and/or relationship.

Changes of spatial properties like location, shape, size, orientation and so on.

Changes of thematic properties i.e. changes of values of attributes.

In order to detect these changes, Peuquet [6] characterizes spatial-temporal data in three main components: space (where), time (when) and objects (what). These components are co-related, (see Figure 2) which means that the combination of these components allows one to ask the following questions:

- **"when" + "where" → "what"** describe the object or set of objects (what) that are present at a given location or set of locations (where) at a given time (when).
- **"when" + "what" → "where"** describe the location or set of locations (where) occupied by a given object or set of objects (what) at a given time (when).
- **"where" + "what" → "when"** describe the times or set of times (when) that a given object or set of objects (what) occupied a given location or set of locations (where).

Andrienko et al. [7] takes it a step further and argues that spatio-temporal data analysis should also consider search levels, elementary and general, whether we are respectively focusing on one object or multiple objects, and cognitive operations, whenever we want to identify or compare them. Furthermore, breaking data components into "when" and "what+where" and combining this with the latter search and cognitive levels, we can obtain the following extended set of questions:

Elementary "when" and elementary "what + where" describe the characteristics of an object (what) that is present at a given location at a location (where) at a given time (when), e.g. *which bus does user A at takes at 10 am at the bus station?*.

Elementary "when" and general "what + where" describe the situation (general what + where) at the given time moment (when), e.g. *are user A and B near each other at 10 am?*.

General "when" and elementary "what + where" describe the dynamics of characteristics of an object at a certain location (elementary what + where) over time (general when), e.g. *in which stations was user A during the morning?*.

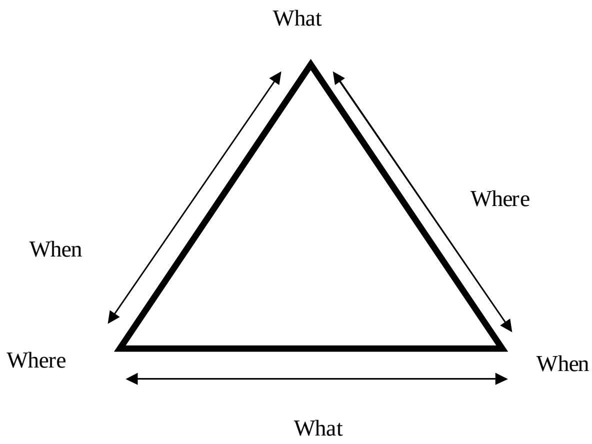

Fig. 2: Questions while exploring changes on spatio-temporal data [6].

General "when" and general "what + where" describe the evolution of the overall situation (general what + where) over time (general when), e.g. *which were the most visited locations during the afternoon?*.

2.2 Visualization techniques of spatio-temporal data

In order to analyze spatio-temporal data, some sort of visual exploration techniques are needed [3]. These are considered as an effective approach to provide material for human's perception to map temporal information with spatio-temporal changes. In essence, visual exploration implies the visualization of data.

Keim et al. [8] classifies visualization as scientific and information visualization. Scientific visualization is the visualization of scientific data that have spatial and time references. Information visualization stands for visualization of abstract data that has neither spatial nor time references.

This work addresses geovisualization, a type of visualization that integrates approaches from scientific and information visualization, cartography, image analysis, exploratory data analysis, and GIS, to provide theory, methods and tools for visual exploration, analysis, synthesis, and presentation of spatiõtemporal data [9]. One of the most common tools in geovisualization are temporal maps. Kraak and MacEachren [9] define temporal maps as a representation or abstraction of changes in geographical reality: a tool (that is visual, digital or tactile) for presenting geographical information whose locational and/or attribute components change over time.

Monmonier [10] distinguish four categories of temporal maps: (i) single static maps (e.g. temporal symbols, temporal aggregations, maps representing movements and changes by rates or absolute values); (ii) multiple static maps (e.g.

interconnection of maps and statistical graphics); and (iii) multiple dynamic maps (e.g. animations, interactive graphic analyses).

Kraak et al. [11] have a similar classification, whereas they join the latter two categories as follows: (i) single maps; (ii) multiple maps; and (iii) animated maps. The first two categories cover both static and dynamic maps (e.g. blinking map symbols).

2.3 Single Maps

A static representation of a set of events on two dimensional maps using a graphic sign system (complex point symbols, temporal glyphs, generalized trend-surface, flow-linkage maps, etc.) to depict movement [10].

Sign systems on single maps typically use lines and arrows to represent the spatio-temporal properties of a set of objects from their starting points to their destinations [3]. Pre-defined shapes and labels may also be used to represent the occurrence of different events or value changes (e.g. growth of population) during movement. Moreover, other visual attributes such as color, stroke width, and transparency may also be used to characterize events or changes.

Therefore, single maps are particularly useful to visualize spatio-temporal data on a specific moment or as an overall picture. Due to its static property the user lacks the effect of movement and ability to navigate through time and understand the relations and how data mutates over time.

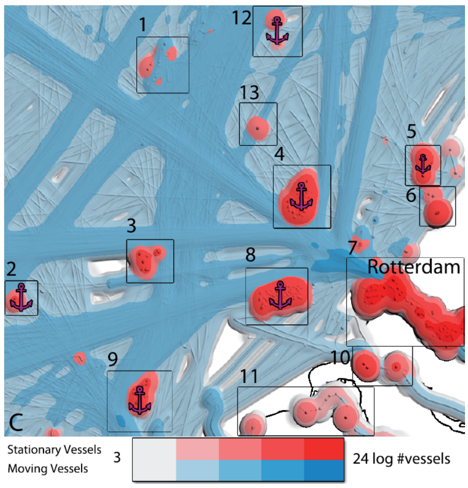

Fig. 3: A vessel density single map classifying the behavior of slow moving vessels in front of Rotterdam harbor over the period of one week. Common transit and stationary areas are represented respectively in gradual blue and red colors and custom shapes (source [12]).

2.4 Animated Maps and Multiple Maps

Besides the visual difference, multiple maps and animated maps, share the same approach to display spatio-temporal data (see Figure 4). In both cases, a set of temporal maps display different data states over time [3]. In multiple maps, a set of temporal maps (frames) is displayed with the frames juxtaposed to each other. This technique is useful to quickly visualize and compare a few simple static maps. The task becomes much more complex in the presence of many frames because it is difficult to read and mentally compare all the juxtaposed frames [13]. However, in animated maps, the frames are displayed sequentially in a single view. A classic example of animated maps are weather forecast maps on television, which through animation allows the viewer to visualize the atmosphere conditions changing during a period of time.

Fig. 4: Multiple map representation (A) where each maps represents one day of recorded movement and all maps are visible. Animated map representation (B) where each map represents an instant in time, and only one is displayed at that time (source [3]).

Animation in geovisualization is about visualizing spatio-temporal data components changes. It can depict change and interrelations among space, attributes, and time [14]. Animations are useful in revealing trends, processes and subtle spatio-temporal patterns that are not evident in static representation. Dorling and Openshaw [13] demonstrated the crucial difference that animation in temporal maps makes, when they investigated childhood leukemia rates in northern England during twenty years. Until then, using classic static visualizations to plot the occurrence of these cases, no apparent pattern could be seen and the only conclusion was that these cases were isolated sparse surge points in a random distribution. As soon as the time component was taken into consideration, the animation revealed previously unrecognized hot-spots (localized both in space and time) as well as their rising and falling in the cities of Newcastle and Manchester.

Animation can also be used to visualize routes of moving objects — trajectory data. Unlike static representations, animation can clearly represent details about speed, acceleration, and interaction of individual objects throughout different periods of time. To visualize the animation of a set of objects, the following approaches can be used [7]:

Snapshot in time is the simplest approach that places all the objects at their location at a specific time. This approach may not be convenient when used alone to visualize more than one object;

Movement history involves animating the objects and their trajectories from their starting points. The animation ends with the trajectories shown. This approach is especially useful to understand the evolution and interaction of the observed objects without losing track of them. However, in case of long and complex trajectories, the visualization can become too saturated;

Time window acts as the previous approach, with the only difference being that only a portion of the trajectories are shown, based on defined limits, just as the white trails behind an airplane. This change solves the drawback of the movement history approach for complex trajectories.

For a user of an animated map, it is important to have tools, which permit interaction while viewing the animation [15]. Therefore, a temporal legend plays an important role in an animated map. This element is not only important to locate the viewer in time and to understand how data interrelates, but it also works as a navigation tool to control the animation itself [14]. To enable this dynamic control, a temporal legend is typically composed with several actions that provide playing, pausing, and travel in time functionalities.

The style of a temporal legend may differ according to the spatio-temporal phenomena displayed by the animation, the nature of the temporal queries that users are expected to make, and the knowledge schema concerning spatio-temporal entities that we are trying to prompt [14]. For instance, a round clock or clock-like temporal legend is better suited to depict data measured in a cyclic time, such as the day and seasons, because the clock ticks already represent cycles in time. However, temporal location in full time span is not clearly depicted. In this case, a slider bar is naturally better suited to depict linear time with a marker designating the current temporal location (see Figure 5). Numerical legends are also essential in slider bars to identify temporal location (e.g. Saturday, July 20 2014 4:27 PM).

Although it is recommended to have the best suitable style for a temporal legend for better understanding of the viewer, studies showed that independently of the choice no significant impacts exist on performance, response time or correctness of results [16].

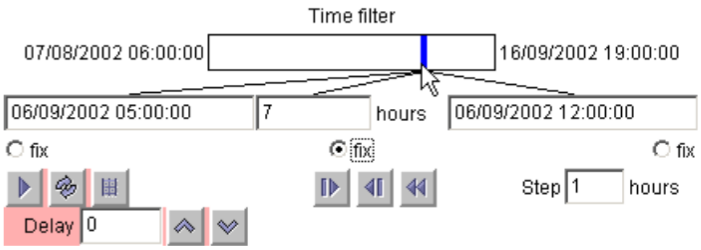

Fig. 5: A temporal legend in a slider bar style with playing, pausing, and travel in time functionalities (source [4]).

2.5 Space-time cube

Another visualization technique that has been receiving a lot of attention in the last few years is the space-time cube. Proposed by Hagerstrand in 1970 [17], this technique supports the idea that time and space are ultimately related. Using a three-dimensional diagram, the space-time cube uses two dimensions to represent geographical space (typically the x–y axis) and a third dimension (usually the z axis) to represent time (see Figure 6). The movement of an object or a set of objects is shown as a three-dimensional line connecting successive positions — the space-time path. The inclination of the line segments indicates the speed of the object, i.e. gradual rise means high speed, steep pitch signifies slow movement, and vertical segments correspond to time intervals without movement [4].

Beforehand, creating these diagrams was hard because it involved many drawing skills to accurately draw a three-dimensional temporal map with space-time paths on a two-dimensional paper. Nowadays, thanks to modern computer graphic technologies, three-dimensional visualizations are commonplace and easily accomplished. Therefore, in recent years a lot of research has been done around this technique.

The greatest advantage of this technique is its applicability in various different types of analyses and data, especially when analyzing complex spatio-temporal patterns [18]. In addition, since time is represented in a spatial position, it is not required to have a visual tool, like animations, to perceive movement over time. Nevertheless, this technique might not be helpful for novice users because, since humans are typically used to analyze two-dimensional maps, this technique is not as naturally perceived as the previous ones. Furthermore, due to the human's three-dimensional perception issues this visualization might lead to problems of metric values misinterpretation and information occlusion [19].

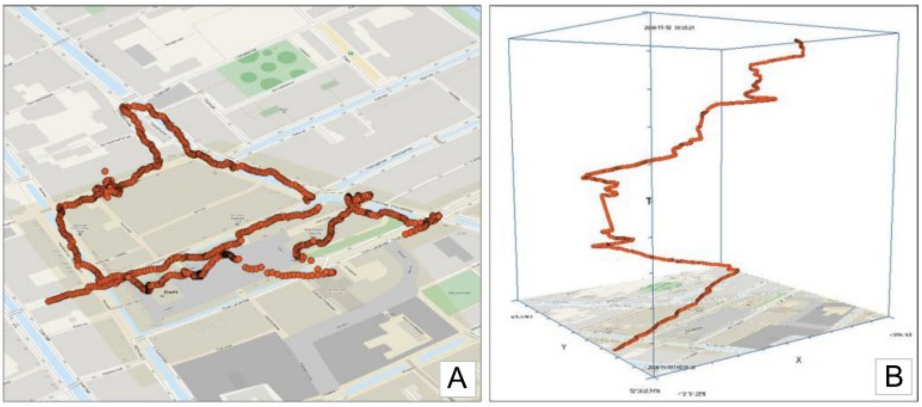

Fig. 6: Trajectory data visualized in a single static map (A) and in a space-time cube map (B) with time and space depicted in the z and x-y axis respectively (source [20]).

3 Dataset overview

The dataset used in this work is made of GPS trajectories collected in the Geolife project by Microsoft Research Asia, tracking 182 users over a period of five years (i.e. from April 2007 to August 2012). Although the dataset is wildly distributed in over 30 cities of China and even in some cities located in the USA and Europe, the majority of the data was created in Beijing, China.

Each GPS trajectory in this dataset is represented by a sequence of time-stamped points, each of them containing the information of latitude, longitude and altitude. The complete dataset contains 17,621 trajectories with a total distance of about 1.2 million kilometers and a total duration of 48,000+ hours. Approximately 91 percent of the trajectories are logged in a dense representation, e.g. every 1–5 seconds or every 5–10 meters per point. In the data collection program, a portion of users have carried a GPS logger for years, while some of the others only have a trajectory dataset of a few weeks (see Figure 7).

The dataset recorded a broad range of users' outdoor movements, including not only life routines like go home and go to work but also some entertainments and sports activities, such as shopping, sightseeing, dining, hiking, and cycling. There is portion of the dataset where each trajectory has a set of transportation mode labels, such as by driving, taking a bus, riding a bike and walking.

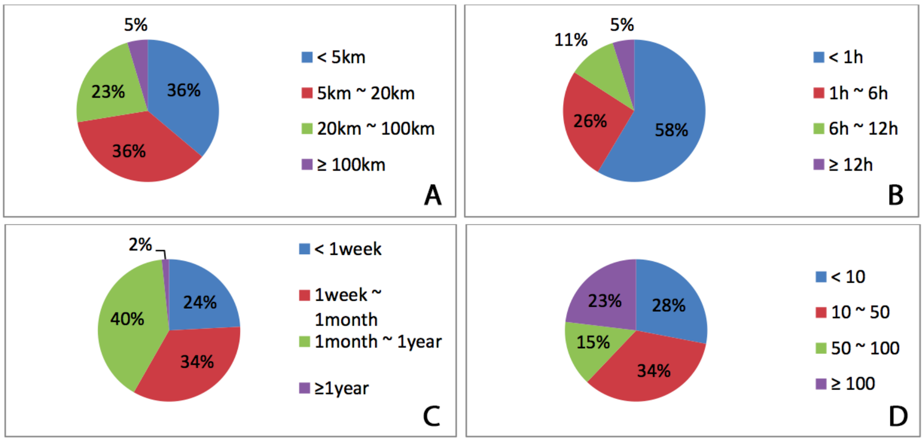

Fig. 7: Distributions of distance (A), duration of the trajectories (B), duration of data collection (C), and number of trajectories collected by each user (D).

4 Methodology and Solution Architecture

The goal of this work required a research methodology to unveil a novel spatio-temporal visualization tool for animated maps. It was necessary to review several domain topics related with spatio-temporal data analysis and visualization techniques, and study modern web technologies that could help to build this work solution proposal.

4.1 Research methodology roadmap

After reviewing the status quo of these domain areas and defining the objectives of this work, a research methodology roadmap was established with the following steps:

1. Perform a comprehensive literature on the main concepts that could help shape the solution proposal: types of temporal maps, visualization techniques and tools, animated maps, animations, temporal legends, temporal maps legend shapes, spatio-temporal data mining, etc.
2. Next step involved a state-of-the-art analysis concerning modern web standards for data visualization and animation using non-Adobe Flash technologies such as CSS3, SVG and HTML5.
3. The research finishes with topics consolidations and refinements from all information sources, combining the gathered research towards the proposed solution.
4. Prior to the final solution it was necessary to analyze the supplied dataset and create an extra tool that would allow the sampling and extraction of data to the desired output format.

5. In order to prove the feasibility of this work, an online animated map to visualize trajectory data was created, and a proof-of-concept was developed using D3.js, Leaflet.js, and Crossfilter and other minor libraries.
6. Finally, this solution proposal was tested and evaluated to prove its performance, usability, and utility.

4.2 Solution proposal

As research reveals, two-dimensional visualization techniques remain the clearest and easiest to be perceived by all users. From the two-dimensional geovisualization techniques discussed before, animated maps was the obvious choice for this work, due to its ability to display multiple maps that show the interrelation between the spatio-temporal data components (space, time, and attributes) of a set of objects in a single view.

This work visualization tool includes an animated map that enables the viewer to visualize and compare trajectory data, find patterns, comprehend behaviors, and discover knowledge from the observable objects, simply through the tracking of the objects movement. In addition, a temporal slider bar enables the user to locate and restrict data in time and to navigate through time (see Figure 8).

The innovative part of this tool is that the temporal slider bar and the animated map are intrinsically connected. The temporal slider bar defines the observable time range and the object's latest position and trajectory trail within that period. The user can in real-time dynamically resize or shift this period and immediately update the map data. This real-time interaction results in a visual animation showing the space location of the objects changing as one controls the slider bar. In the animated map, within the active time period, a circle symbolizes each object's latest position and its attached multi-segment line represents the object's trail up to its latest position. Each color represents a different object.

As with any tool, there are limitations to its use. This approach is not a silver bullet and it is not able to answer all kind of data analysis questions. Only a certain set of user cases can be performed. This tool focuses on providing the viewer with the state of the data (frame) in a specific time period. For instance, it is not easy to determine the velocity of the moving objects or compare frames from sparse periods in time.

4.3 Solution architecture

The ultimate goal of this work was to be able to develop the discussed visualization tool in an online environment where a user would be able to visualize his data just by using a simple browser and without having to install any kind of third-party software. This goal did not even require the use Adobe Flash[1], an

[1] Adobe Flash is a multimedia and software platform used for creating vector graphics, animation, games and rich Internet applications (RIAs) that can be viewed, played and executed in Adobe Flash Player. Flash is frequently used to add streamed video

application used for many years to develop applications and visual animations on the web. Currently, the web world is facing a shift from Flash applications to open and cross platform HTML5 ones. The reasons for leaving Flash behind are varied, and range from the heaviness that the Flash plug-in and animations made in Flash have, constant Flash website updates, cross platform issues, SEO (Search Engine Optimization) concerns, and others [21]. The fact that Apple won't allow Flash on its devices, and that Microsoft is also releasing a web browser that won't support Flash, also hasn't helped the adoption of this once popular plug-in in new applications.

Before any development a small tool in Python was created to export data from the dataset in the desired output format (CSV) and from specific time ranges (e.g. one week of the entire dataset), sampling time periods (e.g. exporting only trajectories with at least 5 minutes difference) and users (e.g. export only the first 5, 50 or 100 user data). After obtaining a usable sampled dataset, the tool displays the data and allows for interaction.

During the development of this proof-of-concept only open source libraries were used. The following libraries were essential to create the user interface of the tool, manipulate data on the browser-side, display cartography maps, and others:

SVG is an XML-based vector image format for two-dimensional graphics with support for interactivity and animation. The SVG specification is an open standard developed by the World Wide Web Consortium (W3C) since 1999. All major modern web browsers — including Mozilla Firefox, Internet Explorer, Google Chrome, Opera, and Safari — have at least some degree of SVG rendering support.

D3.js is a JavaScript library for manipulating documents. This library emphasizes web standards (HTML5, SVG and CSS) and uses the full capabilities of modern browsers to build data-driven powerful visualization components and Document Object Model (DOM) manipulation, i.e., it binds arbitrary data to objects in a web document and applies transformations to the document based on the data. This library was especially useful to animate the raw SVG elements without having to deal with them by hand.

Leaflet.js is a modern open-source JavaScript library for mobile-friendly interactive maps. It works efficiently across all major desktop and mobile platforms out of the box, taking advantage of HTML5 and CSS3. It was essential to display the cartographic map and to convert GPS coordinates into positions on the screen.

Crossfilter is a JavaScript library that acts like a client-side OLAP server, quickly grouping, filtering, and aggregating rows of raw data very quickly (less than 30ms), even with datasets containing a million or more records. It was fundamental to manipulate the dataset in the browser, performing filter and counting operations when loading and when the user interacts with the slider bard.

---

or audio players, advertisement and interactive multimedia content to web pages, although usage of Flash on websites is declining.

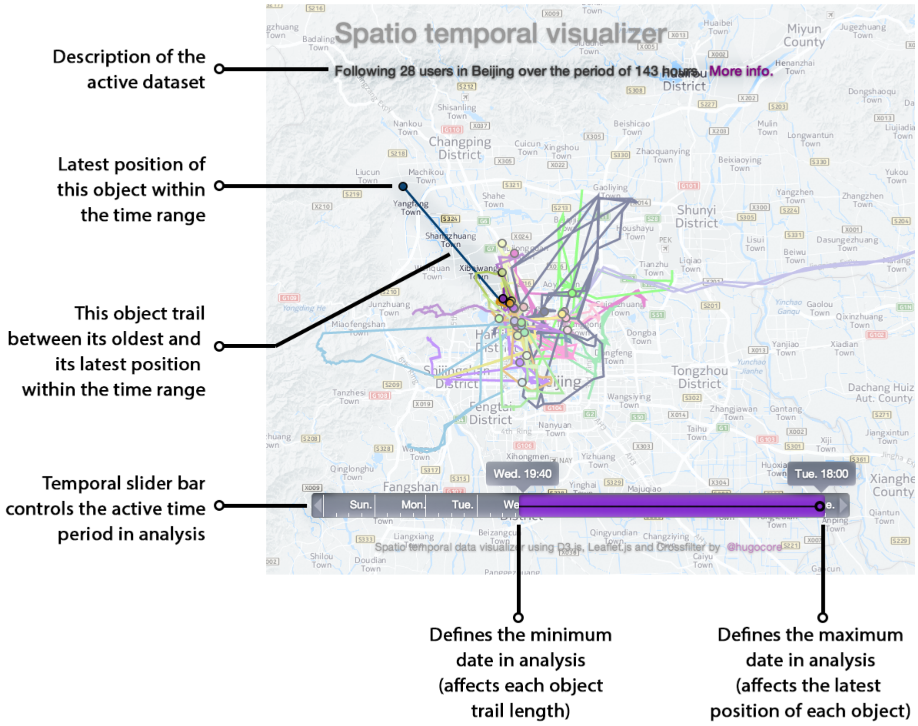

Fig. 8: Description of the user interface of this work visualization tool.

The visualization tool is not fixed for a specific time and space location. Both parameters can be setup in the source code (js/main.js). The variables *minDate* and *maxDate* define the minimum and maximum dates that limits the temporal slider bar. The variables *startDate* and *endDate* define the initial period of time that the slider bar will restrict.

Configuring the temporal slider bar

```
...
minDate = formatDate("2008-10-01 00:00:00");
maxDate = formatDate("2008-10-28 23:59:59");
startDate = formatDate("2008-10-16 21:15:00");
endDate = formatDate("2008-10-23 21:15:00");
initialPosition = [39.94403, 116.407526]; // beijing
...
```

Besides configuring the tool's user interface one must also setup the location of the dataset. This dataset must be a CSV or JSON file with the following scheme: "user" (id of the object), "lat" (latitude of the trajectory), "lng" (longitude of the trajectory), and "timestamp" (the unix timestamp of the trajectory, i.e., the number of seconds since the January 1st, 1970 at UTC).

Location of the CSV dataset

```
...
d3.csv("csv/182-29out-5min.csv", function(collection) {
...
```

5 Results and Evaluation

As stated before, this work goal was to provide a spatio-temporal data visualization tool that could identify patterns, compare and understand individual's behaviors and produce knowledge within a specific period of time. To evaluate this tool, we used Andrienko et al. [7] spatio-temporal data analysis extended framework to answer a few type questions and prove that we can obtain new knowledge as intended.

5.1 Elementary "when" and elementary "what +where"

Q: Which part of Beijing is the most visited one (hotspot) during a week of work (e.g. 20th — 24th Oct. 2008)?

After adjusting the temporal slider bar to the specified time period, we can identify a dense area with many visible trails, marked in red in Figure 9. This area belongs to the district of Haidian, where most of the habitants are students because the government does not allow long periods of living in that district. Speaking to the fact that most habitants are students, when we take a closer look, we can see that most of the trails surround universities in that area, like the Tsinghua University. Therefore, this shows us that most of the individuals in the dataset are students.

5.2 Elementary "when" and general "what +where"

Q: Is there any situation where all the users are relativity located near each other (within the city limits) during the 20th — 24th?

To answer this question, the easiest way is to place the left marker (controller of the trails length) in the first situation where all users are close to each other. In our case, in the beginning of the 20th at 1 am. Next, we extend the right marker (controller of the circles, i.e. the latest position of each individual) until some individual gets out of the city. In our dataset, that is the beginning of Saturday at 1 am. We then conclude that during the entire third working week (20th — 24th) all individuals are near each other (see Figure 10). This meant that all individuals stayed in the city, living and working for the entire week. To find the reason for this we would be required to cross this information with other information such as weather, financial, activities data, or others. But at least, we already know which time period to look for. This knowledge can later be used by external parties. For instance, real-estate companies can discover areas where habitants are living and invest in those areas; event organizers can discover the best periods to organize events where most of the habitants are in the city, and others.

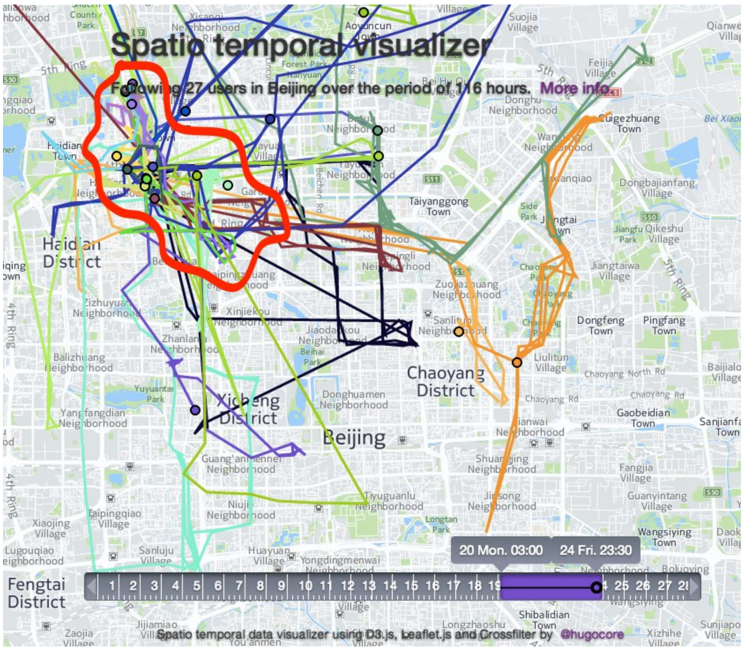

Fig. 9: Visualization displaying the most visited area in Beijing in red (hotspot).

5.3 General “when” and elementary “what + where”

Q: How many individuals went to the nearest big town, Tianjin, during the entire time?

With the time period of the temporal slider bar going from one end to the other, we can visualize all the trajectories that occurred in that city. By padding and zooming the map we can count 3 different trails (see Figure 11). With a total of 38 individuals in the dataset only 3 visited Tianjin (7%), possibly representing that this is not a popular city for the individuals of Beijing.

5.4 General “when” and general “what + where”

Q: What are the farthest locations traveled to by the individuals?

One more time, with the time period of the temporal slider bar going from one end to the other, and after some padding and zooming, we can visualize the extension of all the individual trails during the entire time period (see Figure 12). The visualization shows many remote locations located many kilometers away from Beijing visited by the individuals, such as Lhasa, Chengdu, Longhua, and Hulunbuir. These visits are sparse, with most of the individuals staying within or near the city during the entire month. This information can be used in many ways, for instance, to conduct a study by the transportation services and trip organizers to discover popular destinations and promote trips.

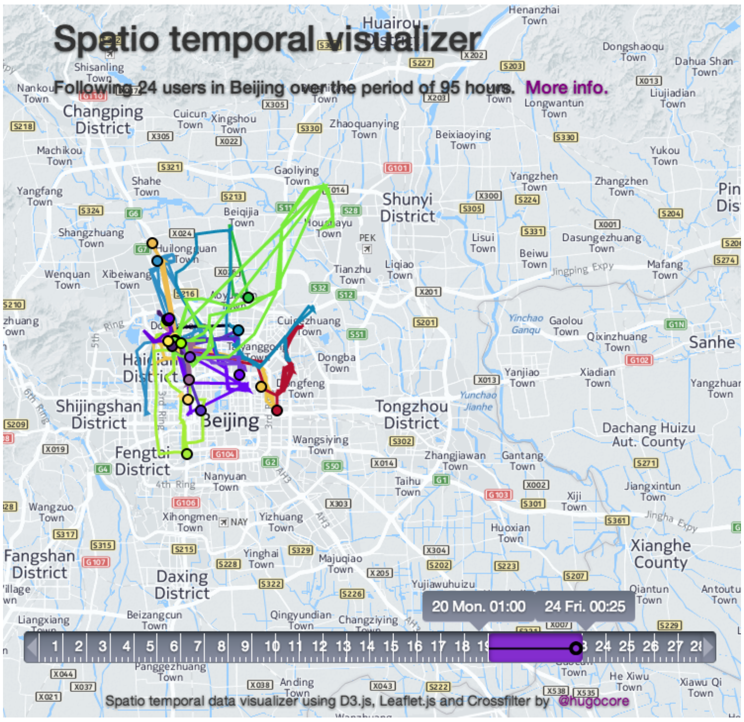

Fig. 10: Visualization displaying a situation where all the users were all close to each other during an entire day or more.

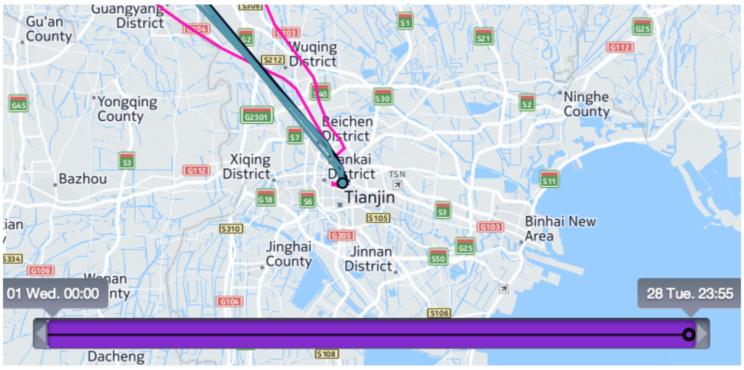

Fig. 11: Visualization displaying how many individuals visited the city of Tianjin.

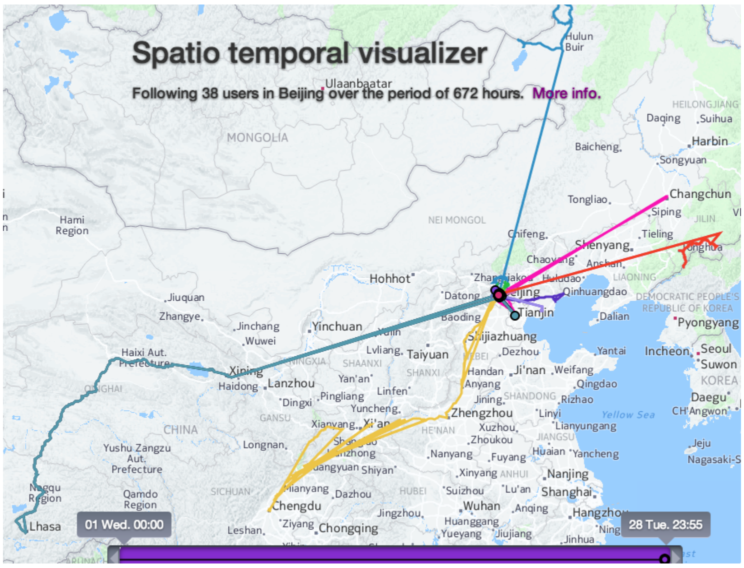

Fig. 12: Visualization displaying the farthest locations traveled by the individuals.

6 Conclusion

Following the current spatio-temporal visualization techniques, the main goal of this work was to create an innovative and user-friendly online visualization tool that enable the identification of patterns, compare and understand behaviors and produce knowledge when focusing on a specific period of time. To achieved this goal, a research methodology roadmap was outlined that involved literature review regarding exploratory analysis and visualization techniques.

Our research showed that animated maps was the visualization technique that better suited the established goal. Therefore, a proof-of-concept tool was developed and evaluated by answering typical spatio-temporal exploratory questions with ease.

It is important to say that neither this tool nor this visualization technique is capable of answering all kind of exploratory questions. The end result became a very good tool to analyze data in one specific time period. However, the major conclusion is that the tool itself should be manually configured to answer different questions in different time spans. The temporal legend bar settings should be proportional to the period of time that we want to analyze. Because the moment we increase the slider bar limits, the harder it becomes to operate the markers to choose a small period of time. In top of that, with larger time periods comes more data, and therefore, it becomes harder to the user to analyze the animated map.

Further work, may involve additional control bars to provide extra functionalities, such as the ability to choose which individuals are active or not; control the temporal slider bar limits without having to edit the source code; and the ability to fade in and out the trails to read the background map layer.

Bibliography

[1] NH Long. Web visualization of trajectory data using web open source visualization libraries. 2010.

[2] Christian Tominski, Heidrun Schumann, Gennady Andrienko, and Natalia Andrienko. Stacking-Based Visualization of Trajectory Attribute Data. (October):1–10, 2012.

[3] T Gonçalves, AP Afonso, and B Martins. Visualization Techniques of Trajectory Data: Challenges and Limitations. *ceur-ws.org*, pages 1–10.

[4] Gennady Andrienko, N Andrienko, and S Wrobel. Visual analytics tools for analysis of movement data. *ACM SIGKDD Explorations ...*, 2007.

[5] Cornelia Adriana Blok. *Monitoring Change: Characteristics of Dynamic Geo-spatial Phenomena for Visual Exploration*, volume 1849 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, Berlin, Heidelberg, November 2000.

[6] Donna J. Peuquet. It's About Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems, 1994.

[7] Natalia Andrienko, Gennady Andrienko, and Peter Gatalsky. Exploratory spatio-temporal visualization: an analytical review. *Journal of Visual Languages & Computing*, 14(6):503–541, December 2003.

[8] Daniel Keim, Gennady Andrienko, Jean Daniel Fekete, Carsten G??rg, J??rn Kohlhammer, and Guy Melan??on. Visual analytics: Definition, process, and challenges. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, volume 4950 LNCS, pages 154–175, 2008.

[9] MJ Kraak and AM MacEachren. Visualization of spatial data's temporal component. In *Spatial Data Handling, Advances in GIS Research*, pages 5–9, 1994.

[10] Mark Monmonier. Strategies for the visualization of geographic time-series data. *...: The International Journal for Geographic Information ...*, 27(1), 1990.

[11] MJ Kraak. The space-time cube revisited from a geovisualization perspective. *Proc. 21st International Cartographic Conference*, (August):10–16, 2003.

[12] Roeland Scheepens, Niels Willems, Huub van de Wetering, and Jarke J. van Wijk. Interactive visualization of multivariate trajectory data with density maps. *2011 IEEE Pacific Visualization Symposium*, pages 147–154, March 2011.

[13] D Dorling and S Openshaw. Using computer animation to visualize space - time patterns. *Environment and Planning B: Planning and Design*, 19(6):639–650, 1992.

[14] MJ Kraak. Cartographic animation and legends for temporal maps: Exploration and or interaction. *...International Cartographic ...*, pages 1–8, 1997.

[15] Mark Monmonier and Myke Gluck. Focus Groups for Design Improvement in Dynamic Cartography, 1994.

[16] RM Edsall, MJ Kraak, AM MacEachren, and DJ Peuquet. Assessing the effectiveness of temporal legends in environmental visualization. *GIS/LIS*, pages 677–685, 1997.

[17] Torsten Hägerstrand. What about people in Regional Science? *Papers of the Regional Science Association*, 24(1):6–21, December 1970.

[18] Lauro Lins, James T Klosowski, and Carlos Scheidegger. Nanocubes for real-time exploration of spatiotemporal datasets. *IEEE transactions on visualization and computer graphics*, 19(12):2456–65, December 2013.

[19] Per Ola Kristensson, Nils Dahlbck, Daniel Anundi, Marius Bjrnstad, Hanna Gillberg, Jonas Haraldsson, Ingrid Mrtensson, Mathias Nordvall, and Josefine Sthl. An evaluation of space time cube representation of spatiotemporal patterns. *IEEE Transactions on Visualization and Computer Graphics*, 15:696–702, 2009.

[20] I Kveladze, S C Vanderspek, and M J Kraak. The Recognition of Temporal Patterns in Pedestrian Behaviour Using Visual Exploration Tools. 2009.

[21] Xing Yan, Lei Yang, Shanzhen Lan, and Xiaolong Tong. Application of HTML5 multimedia. In *2012 International Conference on Computer Science and Information Processing (CSIP)*, pages 871–874. IEEE, August 2012.