

Geovisto: A Toolkit for Generic Geospatial Data Visualization

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Keywords: Geospatial Data, Geovisualizations, Visual Authoring Tools.

Abstract: Today's requirements for visualization of geospatial data are continually rising. Visualization authoring tools provide only limited support for this purpose. The ability to create geovisualizations by non-programmers is often reliant on template editing or visualization authoring tools. However, these tools are often limited either in configuring visual parameters or interaction capabilities. In our work, we identify the main limitations of current tools. Then, we propose design requirements and describe the implementation of Geovisto—a toolkit combining capabilities of the React, Leaflet, and D3.js frameworks in order to provide tools for processing generic geospatial data and creating multilayered reusable map widgets. We demonstrate our approach on two usage scenarios from conceptually different application areas (DDoS attacks from a network monitoring system and COVID-19 pandemics open data). Finally, we discuss the pros and cons of our approach and outline our future work.

1 INTRODUCTION

Many people worldwide use Google Maps or GPS navigation applications like Waze, almost daily. Working with maps and interactive map visualizations have become ubiquitous nowadays. They have many forms and usage scenarios, ranging from simple choropleths used in newspaper articles to specialized analytical applications for disaster management (Huang et al., 2015) or ornitology (Xavier and Dodge, 2014). These so-called geovisualizations work with the *geospatial data*, which combines location information, descriptive attributes (numerical or textual), and optional temporal information (timestamp, duration). The geovisualizations has many forms ranging from point markers placed on the cartographic maps through visualizing connections between them to heatmaps or choropleths. The interactive geovisualizations offer the ability to display data in multiple layers and enable users to explore them at different detail levels through zooming and panning. The layers might be shown at once, enabling the reasoning and supporting analytical tasks. However, identifying the proper visualization method for geospatial data is often tricky, which might lead to ob-

scuring data perspectives essential for the users (Degbelo and Kauppinen, 2018).

With the growing popularity of the open data concept, various geospatial data have become available to the general public. Nevertheless, creating meaningful geovisualizations, especially the interactive ones, predominantly requires programming skills. In the last decade, we can observe growing efforts toward developing visualization authoring systems enabling creation such interactive visualizations for non-programmers (Grammel et al., 2013; Mei et al., 2018). The shortcoming of these tools is that they focus mainly on 2D charts, and there are only a few which target the geovisualizations. Moreover, they offer only limited capabilities in terms of input data or support for multi-layer interaction. We realized that it would be useful to provide the users with a tool that would visualize generic geospatial data, support users in authoring their use cases, and let users analyze their data through a user-friendly interface.

In our work, we address the area of geovisualization authoring tools and contribute to the research body with: a) the identification of limitations and shortcomings of existing tools, b) the prototype implementation of Geovisto—a novel geovisualization authoring toolkit, and c) its demonstration via two usage scenarios.

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The paper is structured as follows. Section 2 overviews the related work and summarizes the shortcomings of current approaches of geovisualization authoring tools. Section 3 presents the design requirements and propose the solution. Section 4 shows the real prototype of the solution and Section 5 demonstrates its applicability on two usage scenarios. Finally, Section 6 discusses the advantages, disadvantages and outlines future research directions, and Section 7 summarizes the paper.

2 RELATED WORK

Listing all geovisualization types is far beyond the scope of this paper. Thus, we first introduce only the most common two-dimensional ones. Next, we present the visualization authoring methods with a particular focus on authoring tools and their limitations.

Most of the web mapping applications available to the general public (e.g., Google Maps, Bing Maps, Open Street Maps) contain only the basic features such as route planning or adding own point markers. Moreover, their spatial analytical functionality is often severely limited or non-existent. Similarly, the geographic information systems (e.g., QGIS¹ or ArcGIS² focus rather on map-making than map use. However, both categories can provide the cartographic layers through public APIs, which can be used in the visualization authoring process.

2.1 Geovisualization Types

Geovisualizations often take advantage of combining multiple layers where each layer presents only a subset of data. The standard base layer is a cartographic map that provides a spatial context. Further, we list the most common types of geospatial data visualization.

Point distribution maps represent the simplest geovisualizations that serve for visualizing datasets of elements containing only the location information (1 a)). If the elements contain the location and one descriptive numerical value, they could be plotted as (*proportional*) *symbol maps* (1 b)). The symbol can be a circle or a glyph whose physical size determines the value. Symbol maps are also useful when the element has two or three descriptive attributes since we can distinguish their size, shape, and color. More advanced modifications enable us to show even more

¹<https://qgis.org/en/site/>

²<https://www.arcgis.com/index.html>

data, e.g., when the glyph symbol is replaced by small 2D charts (e.g., pie/donut/bar charts). When the dataset contains information, not for single locations but the whole regions, *choropleth maps* (or filled maps) are the best option. The color fill of the region represents value (1 c)). Another type of spatial visualization is *heatmaps* (or density maps) that are common, e.g., from weather maps showing the measured temperature or precipitation (1 f)). A particular category is geovisualizations showing routes and paths. Well-known from navigations, the basic *path maps* show direction between two points. However, in the case of flight monitoring websites or computer network visualizations, we can naturally extend the point-to-point to multipoint connections, also known as *spider maps* (1 d)). Finally, by adding the temporal dimension, we can visualize *flow maps*, enabling traffic visualization on the edges (1 e)).

2.2 Geovisualization Authoring Approaches

We can distinguish three general approaches for authoring the interactive visualizations for informative or analytical purposes: a) programming, b) template editing, c) authoring tools and applications.

Programmatic approaches are the most demanding in terms of users' skills and learning curve but offer the most versatility for fine-tuning of visual appearance and interaction capabilities. The frameworks for developing interactive visualizations are usually designed for use in web applications. D3 (Bostock et al., 2011) is one of the most popular imperative frameworks nowadays, and many other libraries use it. It allows mapping the input data to a Document Object Model (DOM) and transforms it via data-driven operations. ProtoVis (Bostock and Heer, 2009) toolkit, also leveraging the imperative paradigm, is based on the idea of decomposing visualizations into hierarchies of visual primitives whose visual properties are data functions. The declarative paradigm frameworks represent Vega (Satyanarayan et al., 2015) and Vega-lite (Satyanarayan et al., 2017). They both provide a set of building blocks for interactive visualization designs. They differ in the level of abstraction and primary use cases. Vega-lite is a high-level grammar build on top of Vega and was designed for rapid prototyping of standard chart types. Backward-compatibility allows programmers to implement more advanced use cases in Vega if needed.

Template editing is the exact opposite of programmatic approaches. It is a well-established way to create simple charts in spreadsheet applications such as Microsoft Excel or Apache OpenOffice. The main

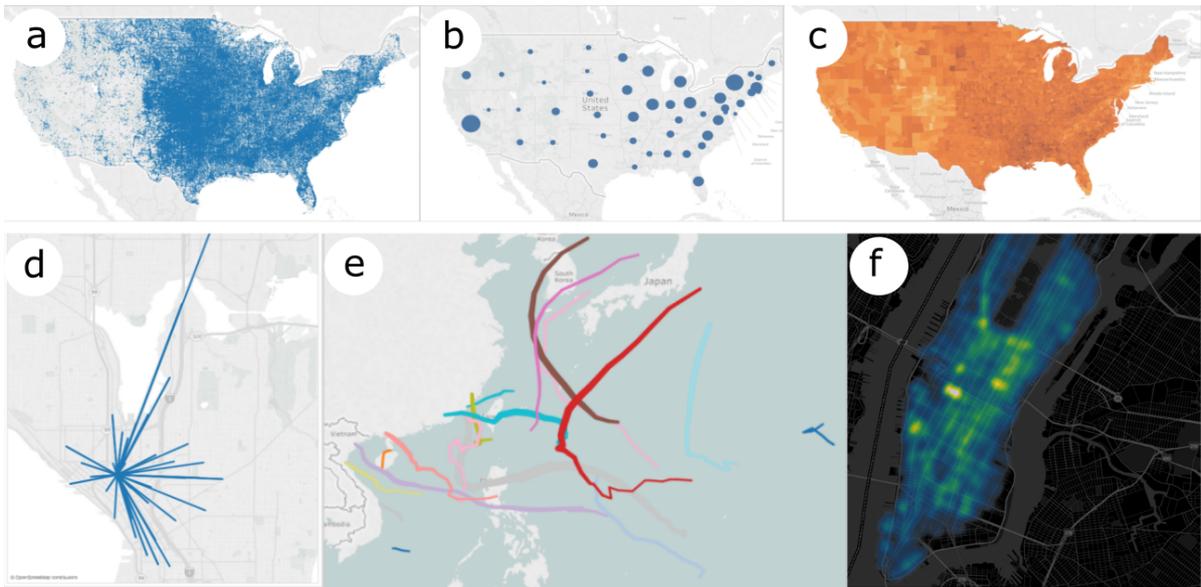


Figure 1: Common geovisualization types: a) point distribution maps; b) proportional symbol map; c) choropleth; d) spider map; e) flow map; f) heatmap. Source: Tableau Software LLC.

characteristics are limited functionality in terms of interaction and ability to visualize tabular-based data in a pre-defined set of charts (e.g., pie charts, bar charts, or choropleths). Users can modify only a basic set of parameters such as color, font, chart shape, or legend position. Template editing is also available in dashboard platforms like Grafana (Grafana Labs, 2020), data analysis tools such as Tableau (Tableau Software, LLC., 2020), or analytical frameworks such as Elasticsearch in the form of extension library (Elasticsearch, 2020). They allow the users to connect their dataset through API. On the other hand, their main disadvantage is that they centralize their platform’s visualization with limited support for their export.

The *authoring tools* build on the advantages of the former two. We can imagine them as advanced graphics software focusing on designing interactive charts. They allow users to create visualizations from basic building blocks that can be widely customized in terms of visual appearance and interaction capabilities through GUI. The output visualizations can be exported as web components and published still without the need for programming skills. Lyra (Satyanarayan and Heer, 2014), Data Illustrator (Liu et al., 2018), or Charticator (Ren et al., 2019) represents such tools or systems. However, their primary focus is on authoring 2D charts, and geospatial data visualization is often limited to data presentation in a single layer. Another downside is that the tools require specific visual design knowledge, which might be limiting for some users. There are also examples of domain-specific visualization authoring applications.

For example, NewsViews (Gao et al., 2014) targets on data journalists to help them create interactive geovisualizations for online news articles. GeoDa Web (Li et al., 2015) platform leverages the cloud storage and computing capabilities and enables data analysts to visualize and publish maps and plots to social media in a user-friendly way. Unlike the general visualization authoring systems, the domain-specific ones are simpler and reduce the need for specific visual design knowledge.

2.3 Limitations of Current Authoring Tools

We aim to generalize the geovisualization authoring tool while focusing on ease of use for professional and novice users. In general, we identified three limitations of the current tools that we address in our work.

Tabular data as the primary input format. Most of the tools expect the data in a tabular format (e.g., CSV), where columns are attributes (or domains) of elements in rows. However, many of the recent data sets are in hierarchical object formats such as JSON or NoSQL databases. For these, additional data transformation or preprocessing is necessary before their use in visualizations. Our goal is to allow users to upload arbitrary geospatial data in an object-oriented format and select the visualization attributes.

Limited Number of Configuration Options. Since the existing tools focus mainly on general 2D chart visualizations, the list of available geovisualization types and their configuration options are narrow. The most

frequent are choropleths, heatmaps, or spider maps. As a result, the user can often display only a few data attributes. Our goal is to enable a combination of visualization types in multiple layers and let users decide which suits their needs.

Limited Interaction Capabilities. Finally, current tools provide only limited interaction capabilities with visualized geospatial data such as their filtering or region-based selection. Our goal is to let users configure the output geovisualization in line with the expected usage and allow them to set multi-layer interaction capabilities and cross-layer data linkage.

We propose Geovisto—the geovisualization authoring toolkit, which enables configuring geospatial data visualizations for use in web-based dashboard applications or as a part of visual analytics workflows. In the remainder, we present its design and prototype implementation. Two usage scenarios demonstrate its applicability.

3 GEOVISTO DESIGN AND IMPLEMENTATION

The main idea of Geovisto is based on (Few, 2006) who recommends presenting the same data in different perspectives, but in one visualization with multiple data layers. Such approach saves screen space, emphasize data contextualization, and streamline discovering hidden relations in the data.

Based on a critical reflection of the related work and limitations of current tools and applications, we defined four design requirements:

- Geovisto’s *user interface* should enable user-defined data mapping to multiple configurable layers.
- Geovisto should automatically transform the input data to a generic *data model* and served to the user through the UI.
- Geovisto should enable the export and import of user-defined *map configurations*.
- Geovisto should follow the component-based *architecture* principles, which enable its future extensibility.

In the remainder, we discuss design decisions and implementation details related to these design requirements.

3.1 User Interface

Since we focus on geospatial data, we have chosen the zoomable world map as our multilayer diagram’s

core. The ability to zoom and move in the map improves the scalability of the widget. It can be used for different purposes, such as visualization of global data on world countries’ level or visualization of detailed data presenting some regional aspects. This is an advantage in contrast to the single-purpose maps. It also provides drill-down action, which improves the comprehensibility of data.

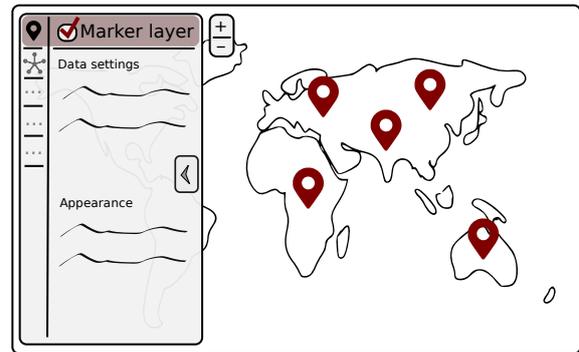


Figure 2: Geovisto UI design sketch. The left sidebar is composed of tabs managing the settings of particular map layers. It allows the users to show or hide specific layers (e.g., the marker layer demonstrated by the figure) and configures the data they display.

The user interface is sketched in Figure 2. It is composed of independent layers that display data from different perspectives (e.g., choropleth, markers, connections). Since the layers are independent, it is up to the user which of them will be included in the map.

3.2 Data Model

Considering various data models can represent the data, it is essential to create a mechanism for processing such data models. We need to provide the ability to choose the data domains and bind them to the map layers’ visual dimensions. Examples of problem solutions can be seen in the well-known visualization software. Grafana provides a text editor to assemble queries to various database systems. Tableau allows a drag-n-drop tool to map specific data columns to the selected chart characteristics. Our approach is similar to those examples. Every map layer provides the list of visual dimensions, which can be associated with data domains. The users can, manually, select the data domains using the layer settings provided by the map sidebar. In contrast to existing authoring tools, this approach focuses only on geospatial data. Users can work with multiple data domains representing geographic location formats (such as the ISO 3166 country codes) and use them in various use cases.

In contrast to the mentioned visualization software, we instead try to provide a standalone reusable widget that can be placed in a custom web front-end, rather than provide a complex monolithic visualization system. Hence, we work instead with non-tabular data structures, which can be seen in data formats like JSON or XML. This can be useful, especially for the quick processing and visualization of custom serialized data provided by web APIs (like REST API).

Since the chosen non-tabular formats are not flat structures, we do a recursive preprocessing of the data to construct a valid data model representing data domains. Then, we provide a list of the data domains to the users. Figure 3 shows an example demonstrating the principle.

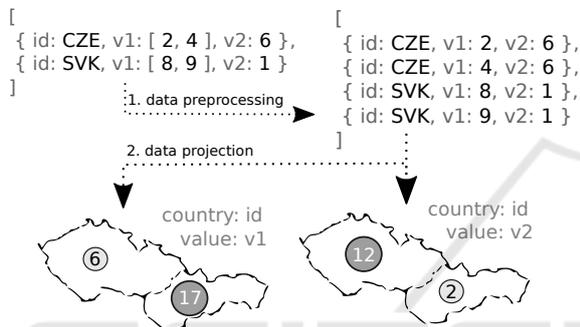


Figure 3: An example of data composed of two records stored in the pseudo-JSON format. Since the records contain nested lists, they need to be preprocessed first. They are expanded into four records represented by all combinations of the values. This representation is characterized by data domains that can be mapped into visual dimensions. The figure shows two different projections and aggregation of data.

3.3 Map Configuration

Geovisto enables to create views that relate to the specific use cases. An example might be the visualization of network anomalies in a particular region or a country’s pandemic situation. Then, these views can be used with different datasets. Our approach provides the ability to prepare such views and export their configurations for further use. Every configuration includes selecting data domains and visual settings of the map (e.g., zoom, position, filters). Besides that, the map configuration defines whether its state can be modified via the map sidebar.

The map configuration can be either exported and imported. The users can use the configuration with different datasets of the same data model. UI designers can also customize the data visualizations without the programming skills and export the configurations for further use by end-users (see Figure 4).

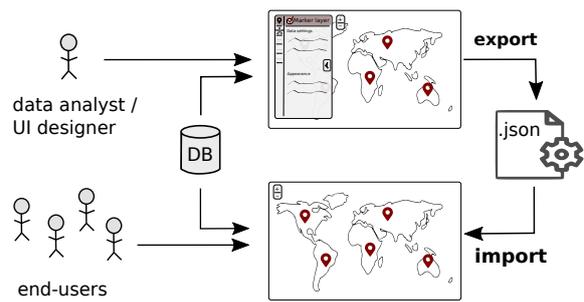


Figure 4: Illustration of visualization authoring and configuration sharing workflow in Geovisto. First, the UI designer creates a projection of the data into the map layers and exports the configuration (in the JSON file). This configuration can then be provided directly to the end-users or the programmers developing the web front-end.

3.4 Architecture

Figure 5 provide a high-level architectural overview. The component-based architecture helps to maximize the scalability and enables the implementation of new geovisualization layers in the future. The toolkit provides a web component implemented in ReactJS³, Leaflet⁴ and D3.js⁵. The toolkit, thus, can be shared as a standalone ReactJS library and included as a widget in third-party web applications. The prototype implements a simple form allowing users to specify their dataset in JSON file and import/export map configurations.

There are two types of input data:

- 1. Geographical Data:** the specification of polygons and their centroids represented in GeoJSON format. The prototype uses the specification of world countries published by J. Sundström⁶ but it can be replaced with generic specifications. The only requirement is that every GeoJSON feature must contain a polygon identifier (e.g., country code), which is needed to connect the geographical data with the dataset.
- 2. Dataset:** the values stored in a serialized format (JSON). There should be at least one data domain representing an identifier of the geographical feature (e.g., country code).

The component renders the base map, whose core is based on Leaflet. The library provides functions for the projection of geographic features onto the map and interaction capabilities with the base map.

³<https://reactjs.org/>

⁴Leaflet (<https://leafletjs.com/>) is a Javascript library for developing interactive maps.

⁵<https://d3js.org/>

⁶<https://github.com/johan/world.geo.json>

The library also provides API for processing GeoJSON and integrating additional overlay layers (usually vector objects that are rendered in the form of SVG elements—e.g., country polygons, connections, markers). We use this to implement map layers that display particular data perspectives (see Section 4). Geovisto implements the infrastructure for enabling and management of these layers. It also handles events invoked by the map layers (user interaction) and ships them to other layers, which can process them (since the map layers are independent). We also use several Leaflet plugins (e.g., the leaflet-sidebar-v2⁷ for the sidebar control) and the D3.js library to render custom layer items.

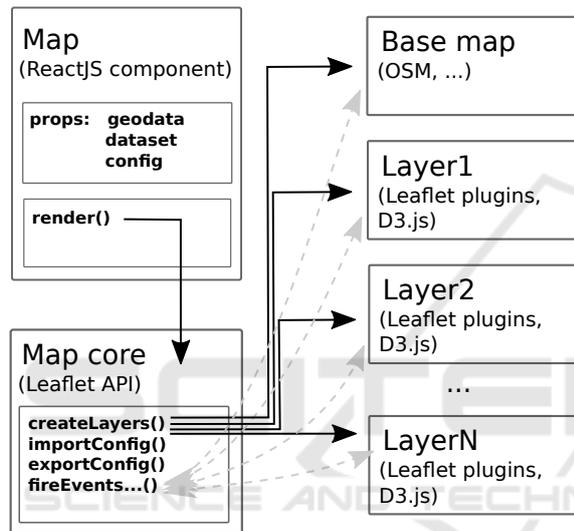


Figure 5: Geovisto architecture overview. The map component renders a Leaflet-based map composed of map layers—usually SVG elements generated via the D3.js library. The map layers are independent of each other and communicate via events. The base map represents a cartographic layer provided through the open APIs (e.g., OpenStreetMap).

4 GEOVISTO PROTOTYPE FEATURES

Currently, the Geovisto prototype contains the choropleth, marker, and connection layers. Besides them, it includes the map layer, which can show a real-world map based on available providers⁸ (e.g., OpenStreetMaps, CARTO). Also, the map provides tools for filtering and data highlighting. Figure 6 shows the user interface.

⁷<https://github.com/noerw/leaflet-sidebar-v2>

⁸<https://leaflet-extras.github.io/leaflet-providers/preview/>

4.1 Choropleth Layer

The choropleth layer provides the possibility to use GeoJSON specifications of polygons representing geographic regions and link them with the data. Unlike basic choropleth widgets, our implementation can process custom definitions of geographic areas. Primarily, we work with the specification of world countries. However, different GeoJSON files can be used, as described in Section 3. The advantage of this approach is the higher scalability of the layer. We can use the layer in different situations and detail (e.g., countries, districts, custom areas). We can also adjust it according to the foreign policy of specific countries (e.g., visualization of disputed territories).

The layer provides two visual dimensions: the *country* should be linked with the data domain representing the geographic feature identifier; the *value* should be paired with the data domain values the user wants to display. The values paired with the same region identifiers are aggregated according to the *aggregation* function (e.g., sum or count). Color intensities are used to distinguish values between the regions. Figure 6 depicts an example of a choropleth displaying the sample numerical values representing the sum of DDoS attacks from individual countries.

4.2 Marker Layer

Another frequent use case is to visualize data related to specific geographic locations via points (*markers*). For this purpose, the widget provides the marker layer. Similarly to the choropleth polygons, every marker has a unique identifier and geographic position (by default, we work with country centroids; hence, we use country codes).

Besides *country*, *value*, and *aggregation*, the user can link the data with the *category* dimension, allowing visualizing categorical data via donut charts. Thanks to the optional selection of data domains, the users can categorize values according to different data domains, analyzing the data.

On the other hand, marker visualization could be problematic when many are close to each other (clutter of markers). We use Leaflet.markercluster plugin⁹ to overcome this issue by clustering the close markers into groups and aggregating the values.

4.3 Connection Layer

The connection layer visualizes relations between geospatial locations in the form of edges. The layer enables the user to select two required dimensions:

⁹<https://github.com/Leaflet/Leaflet.markercluster>

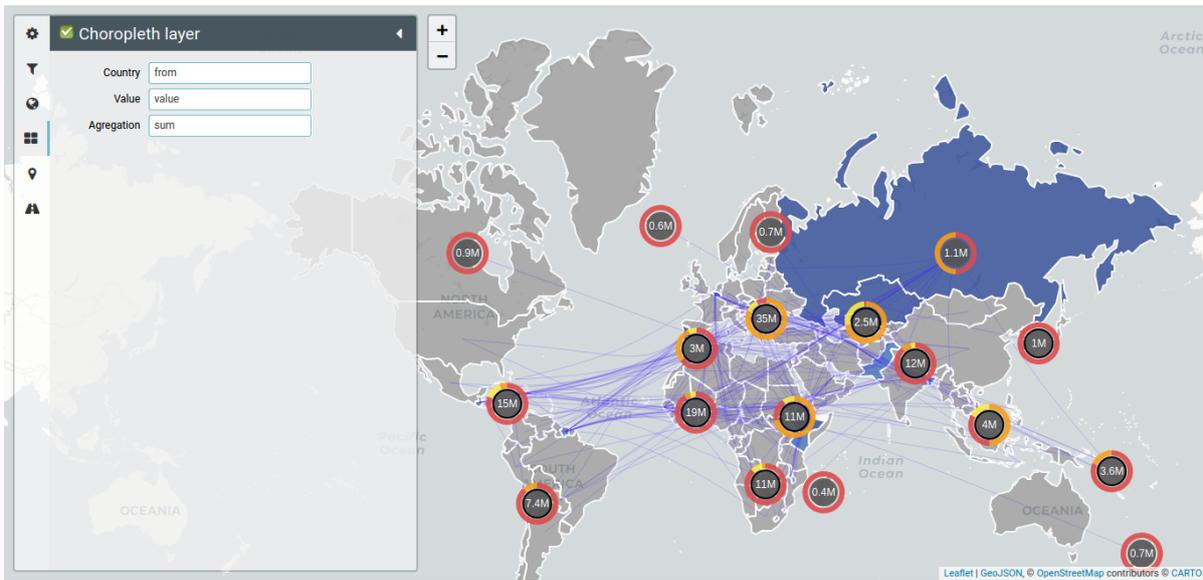


Figure 6: An example of the final map widget. It contains the sidebar (on the left) used for the configuration of layers, the definition of filter rules, and the map’s general setting. This map contains three layers: the choropleth, marker, and connection layer. The example shows the configuration of the choropleth layer. It links the ‘from’ data domain with the ‘country’ visual dimension, the ‘value’ data domain with the ‘value’ visual dimension, and use the ‘sum’ function to aggregate the values.

from and *to*, representing nodes of the rendered edges (by default, we work with the country centroids identified by country codes). Optionally, the user can set the *value*, which affects the strength of the lines.

A common problem of connection maps is their complexity and poor edge placement. (Holten and Van Wijk, 2009) presented a force-directed edge bundling rendering technique that significantly reduces the clutter of edges. S. Engle demonstrated its application¹⁰ on a flight map in the US. The example implements the technique using the *d3-force*¹¹ module of the D3.js library, which “implements a velocity Verlet numerical integrator for simulating physical forces on particles.” In Geovisto, we implemented an SVG overlay layer using the Leaflet API and rendered the SVG elements representing edges using the D3.js library and the *d3-force* module according to Engle’s approach. It was necessary to implement correct projections of the SVG elements into the Leaflet map concerning the map’s zoom and current position. The result provides a comprehensive view of edges that can be zoomed in/out.

4.4 Filters and Highlighting

One of the frequent users’ requirements is the possibility to focus on a specific subset of data. Existing

map tools usually display data from one perspective (e.g., choropleth or markers), and users can filter in these single perspectives only. The possibility to filter the data displayed in one perspective, according to the result of the filtering performed in another perspective is often missing. In our approach, users can select the element in any layer, which results in data filtering of all related elements in other layers (see Figure 7).

The application provides the possibility to specify filter rules as conditional expressions evaluating selected data domains’ values. Also, it allows the users to select specific map elements (e.g., country polygons in a choropleth) and filter all the data related to this selection. Since every map layer is independent, the communication between the layers is implemented via the observer design pattern. Every event passed to the layers contains the information about the source element selected by the user. It consists of the identifier of the geographic element (e.g., country codes) and the layer. The identifiers of geographic elements can be used in more than one layer (e.g., choropleth country, country marker, connection node). Then, the filtering is based on the search of these identifiers through the map layer elements. The search algorithm avoids the cyclic event invocation. The elements found map are highlighted.

¹⁰<https://bl.ocks.org/sjengle/2e58e83685f6d854aa40c7bc546aeb24>

¹¹<https://github.com/d3/d3-force>



Figure 7: Geographic element selection. The selection of Suriname in the choropleth layer invokes an event that is passed to other map layers. The connection layer handles the event, finds, and highlights all the edges which connect Suriname with other countries. This selection invokes another event which contains all the countries connected with Suriname. It affects the choropleth and marker layer, which highlights appropriate countries. Further invocations of events are stopped.

5 USAGE SCENARIOS

In this section, we demonstrate Geovisto on two conceptually different usage scenarios.

5.1 DDoS Attack Analysis

The first scenario was performed in cooperation with Flowmon Networks a.s.¹², a company providing complex tools for automated monitoring, analysis, and network traffic protection. Such examples are analysis of network behavior and encrypted traffic or detecting ransomware and other unknown threats (e.g., DDoS attacks protection). Flowmon provides dashboards for overall monitoring or in-depth analysis of traffic flows (sequences of packets between a source and destination computer). In our joint project, we cooperate on designing and prototyping novel visualizations for their tools. Geovisto is one of them since the input data also contain geographic locations (e.g., source and destination of DDoS attacks, country of origin for public IP addresses).

We collaborated with the company’s UX team on clarifying the user requirements and possible use cases. However, they could hardly imagine the possibilities of how these could be fulfilled. Our solution helped to solve this problem. Since Geovisto can work with custom datasets, we could let the UX

¹²<https://www.flowmon.com/en>

team members play with the prototype independently, which results in generating multiple map configurations providing perspectives of their custom data without any coding knowledge. This approach improved mutual communication and rapidly increased the ability to generate new geovisualization use cases.

Figure 8 presents an example of the use cases. It displays the DDoS monitoring data, so the users can view all attacks and see the source and destination countries of the attacks. Also, they want to emphasize relations between the countries in order to detect the dominant traffic flows. They can then focus on a selected country and analyze specific aspects of the attacks related to this country—e.g., state (active, mitigated, finished). The multilayer map meets the requirements. It can hold either the information about the source of DDoS attacks and the information about their destinations. Then, the connection layer can display the relations between the countries. The users can use the filters to show only a specific subset of data. Finally, they can select a particular country in the choropleth and highlight all the related data presented in the same or other map layers.

Since we implemented the map widget in the form of a reusable component, it can fulfill other use cases (e.g., the analysis of traffic anomalies). The widget can be attached to different endpoints of the back-end REST API, which provide the JSON format data. Using the predefined configuration created by the UX team members, the users will see the arranged map

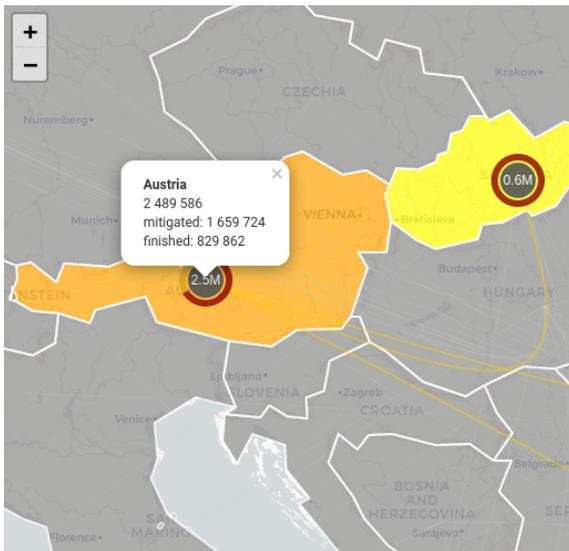


Figure 8: The focus on a particular country and further analysis of the attacking packets. The users can group the data according to different data domains. This example shows the share of mitigated or finished attacks.

layers without manually binding the data domains to the layers’ visual dimensions. If required, the ability to manually redesign the layers and its data can be disabled for the end-users too.

5.2 COVID-19 Pandemic

The second scenario reflects the current world situation. We used the map to visualize the worldwide spread of the COVID-19 disease to demonstrate the widget’s general applicability. We used the data from the rapidapi.com¹³ service and converted them to the JSON format to import them into the map widget. Since the map allows the users to change the data domains, the users can compare the countries from different aspects (sum of confirmed cases, numbers of recoveries, and deaths). They can also combine these views using the choropleth and marker layers. Figure 9 shows an example of the use case.

Similarly, the map could visualize various geospatial indicators (e.g., economic, political, educational).

6 DISCUSSION

In this section, we discuss the advantages and limitations of the prototype implementation based on the presented usage scenarios. Further, we outline our

¹³<https://rapidapi.com/>

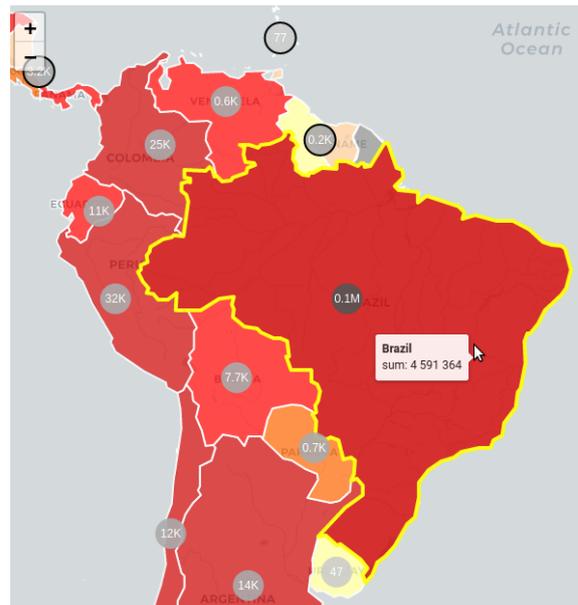


Figure 9: The choropleth layer compares the number of confirmed cases with the disease. The marker layer shows the number of deaths caused by the disease.

plans toward providing Geovisto as a web service for general use.

6.1 Advantages and Limitations

We demonstrated Geovisto applicability in two different usage scenarios. The simple user interface enables even non-programmers to manipulate with the geospatial data and ideate novel contextualization options.

The capability to load custom JSON files and select various data domains allows users to explore information further. Showing more layers at the same time helps the users to see the data in context. The interactive data filtering emphasizes the relations between geographical locations. Map configuration can be serialized and paired with a different dataset using the same model.

The presented usage scenarios are somewhat preliminary evaluation, and we need to evaluate the Geovisto more rigorously. The usage scenarios show only a fragment of geospatial data types that could be visualized. Geovisto is, so far, only a prototype which we plan to extend significantly in the following months. We plan for a series of lab usability studies to improve the user experience. More usage scenarios and case studies are needed to validate the generalization of our approach.

For instance, combining several map layers is limited by the comprehensibility of the widget by people.

The users might be overwhelmed by the data, mostly when inappropriate color combinations are chosen. The z-index of the layers is hardcoded and cannot be changed by the user. Usually, the users should not need to change the default settings (e.g., the marker and connection layers are above the choropleth). In the future, with more layers added, users should be in control of their ordering.

Another limitation relates to the data preprocessing that has to be done to gain a flat data structure, which can be mapped to the visual dimensions of the map layers. Our approach causes enlargement and redundancy of the data. Thanks to that, the data can be processed and quickly. However, it would be useful to design an algorithm that can work with the data without preprocessing and more efficiently.

6.2 Future Work

We can divide further extensions and improvements into three areas. First of all, we want to provide Geovisto as a service that enables users to configure the geovisualizations and include them as widgets on their websites. Currently, we are developing an infrastructure that will be used for managing map configurations datasets. The system will provide the front-end part, used as an application wrapper, including the UI tools to manage user-defined maps. The back-end part will provide a configuration database and API for fetching the configurations remotely. Since the map application works only with the JSON files, we would like to connect to popular relational and non-relational database systems.

The second area deals with layer improvements and creating new ones. Many other map diagram types are suitable for different use cases. We are currently implementing the heatmap layer, which plays a role in the comprehensive data distribution visualization. Also, we will revise the visual appearance of the layers. Since the users can show multiple layers in the map simultaneously, we will pay closer attention to the color pallets used in the layers (e.g., sufficient color contrast, color-blind safe pallet combinations). Also, we plan to add further visual dimensions to the layers as well as controls for manipulation of the layers. By default, the layers support the built-in zoom of the Leaflet library and simple pop-ups. We also add more interactive map legends of value categories.

The third area focuses on Geovisto architecture improvement. We extend its modularity by wrapping the layers shown in Figure 5 into the tool objects. The map core works with multipurpose tools providing various kinds of functionality, such as additional layers or controls (e.g., map legends or menus). For

instance, we develop a timeline control tool, which extends all layers presenting geospatial data with a temporal dimension. It enables to animate spatiotemporal data domains and seek them to the defined time frame. As a result, it will help the user see the evolution of values in individual geographic regions in time.

7 CONCLUSIONS

There are different possibilities of how to visualize geospatial data. Template editing allows users to choose from a pre-defined set of visualizations and configure only their basic parameters. On the other hand, frameworks such as D3.js allow for developing more advanced visualizations but require programming skills. It also requires understanding the chosen mapping library or framework and applying it in a particular situation correctly. The visualization authoring tools combine these two approaches but mostly focus on regular 2D chart visualizations, and their support for visualizing geospatial data is usually limited.

We identified the limitations of current approaches and proposed the prototype of the Geovisto toolkit that addresses them. Our approach combines the advantages of the existing ones and provides a user-friendly interface for non-programmers who want to visualize geospatial data. Geovisto allows the users to load their datasets and map the data domains into multiple map layers. Through user-defined configurations, data filtering, and visual highlighting, users can explore the related data even from different layers. Geovisto is implemented in ReactJS, which allows its integration in third-party web applications and is available under MIT License at GitHub¹⁴.

We demonstrated its applicability in two usage scenarios showed. The multilayered map has appeared to be an excellent way to display geographic locations of network nodes. Flowmon Networks can use the map to display information about DDoS attacks or network traffic anomalies. Interactive filters and the ability to change the data domains allow the users to analyze the data and see the hidden relations better. The second usage scenario showed that the widget could be used for visual analysis of arbitrary geospatial data, such as visualization of the COVID-19 pandemic.

In the future, we would like to improve the user management of map configurations, implement new map layers (such as heatmap) and add the time di-

¹⁴<https://github.com/geovisto>

mension, including animations, which will allow the users to see the evolution of values in time better.

ACKNOWLEDGEMENTS

Jiří Hynek was supported by The Ministry of Education, Youth and Sports from the National Programme of Sustainability (NPU II) project “IT4Innovations excellence in science – LQ1602”.

Jakub Kachlík was supported by the Technology Agency of the Czech Republic project “National Centre of Competence in Cybersecurity” (No. TN01000077).

Vít Rusňák was supported by ERDF “CyberSecurity, CyberCrime and Critical Information Infrastructures Center of Excellence” (No. CZ.02.1.01/0.0/0.0/16_019/0000822) project.

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