Masters Program in **Geospatial Technologies**

VISUALIZING THE VERTICAL CONTEXT OF GEOGRAPHIC LOCATIONS

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VISUALIZING THE VERTICAL CONTEXT OF GEOGRAPHIC LOCATIONS

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VISUALIZING THE VERTICAL CONTEXT OF GEOGRAPHIC LOCATIONS

ABSTRACT

This study addresses the challenge of visualizing the vertical context of geographic locations by creating a web application with innovative visualization techniques. It explores three different visualization techniques to present comprehensive information about geographic locations, covering attributes like administrative, political, geography, weather, and air quality data from two sources: "DBpedia" and "Umweltbundesamt". The visualization techniques used include categorization + scrolling, categorization + semantic panning, and categorization + semantic zooming.

A prototype of the web application was developed to showcase these visualization techniques with two datasets. An evaluation was conducted through a user experiment involving 18 participants divided into six groups. One group interacted with three visualization techniques across one dataset and three tasks. The efficiency of visualization techniques was assessed automatically through a LimeSurvey questionnaire, while effectiveness was gauged by evaluating the accuracy of user responses to questions. Users also provided ratings for enjoyment, usefulness, satisfaction, and ease of use in relation to the visualization techniques. All the gathered data was subsequently subjected to pairwise comparison statistically to identify the statistical advantage using the "bootES" R package.

The findings highlight the strengths and weaknesses of different visualization approaches and best visualization technique among three visualization techniques. Key features for effective visualization approach identified include grouping attributes into main categories and subcategories, arranging similar attributes in close proximity as clusters, and utilizing zooming effects with smooth transitions between attributes.

Keywords

Vertical context of geographic locations, Visualization approaches, Categorization, Scrolling, Semantic panning, Semantic zooming

ACRONYMS

IPA - International Permafrost Association

IASC - International Arctic Science Committee

CSS - Cascading style sheets

IoT - Internet of Things

GIS - Geographic Information Science

ESDA - Exploratory spatial data analysis

EDA - Exploratory data analysis

NO2 - Nitrogen dioxide

SO2 - Sulphur dioxide

O3 - Ozone

CO - Cabon monoxide

SPA - Single Page Application

API - Application Programming Interface

JSON - JavaScript Object Notation

3D - 3-dimensional

WMTS - Web Map Tile Service

GUI - Graphical user interface

SCR - Scrolling baseline approach

SPI - Spiral-type leaflet markers approach

ZOM - Zoomable circle packing approach

D1 - Dbpedia dataset

D2 - UmweltBundesamt dataset

P-Participant

T1 to T6-Task 1 to Task 6

q1 to q5- Question 1 to Question 5

USE-Usefulness, Satisfaction and Ease of Use

CI-Confidence Intervals

SE-Standard error

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1. INTRODUCTION

1.1 Thesis Context

Geographic locations are more than just points on a map; they are complex places with many attributes. Those attributes divide into two essential aspects: the horizontal and vertical contexts. The horizontal context refers to the context established by information about surrounding locations. Exploring the horizontal context involves exploring the spatial dynamics that influence a location. This could range from the physical proximity to other landmarks, the accessibility to transportation networks, to the cultural and economic ties with neighboring regions. It is about the relationships and connections a place has with its immediate surroundings (Goodchild et al., 2012).

The vertical context pertains to the context established by all things that are known about the same location. It involves all the details known about a specific location, encapsulates various attributes such as topography, climate, land use, historical significance, and any other feature that adds depth to the understanding of a location. It is about exploring and understanding various aspects that contribute to the full picture of that geographic location (Goodchild et al., 2012).

The following scenarios elucidate how the vertical context of geographic location is applied across diverse fields. Three examples are: 1. "DBpedia" is a website constructed by extracting structured information from Wikipedia. Users can explore vertical attributes for numerous geographic locations by searching for the location's name, with these attributes presented as rows. e.g. DBpedia website for Berlin[1]. 2. The web application "Umweltbundesamt," hosted by the German Federal Environmental Agency, allows users to generate comprehensive air quality information displayed on a map. Users can filter air pollutant type, date, time and station variables to obtain specific and detailed air quality values. e.g. Air quality data for Nitrogen dioxide at the measuring station located in Berlin Frankfurter Allee[2]. 3. "Arctic Coastal Dynamics" is a database jointly developed by the International Permafrost Association (IPA) and the International Arctic Science Committee (IASC) and this dataset contains Arctic coastal data on coastal morphology, composition, dominant processes, ground ice, and environmental forcing parameters such as wind speed, storm counts, melt season, and wave energy.

[1] https://dbpedia.org/page/Berlin

[2] https://www.umweltbundesamt.de/daten/luft/luftdaten/stationen/eJzrXpScv9B0UXHyQqNFKYmrjAyMjHQNjXSNDReVZC4yNFqUl7rQeFFxyWJDc6MlKYluRXAVRiZAfkg-so7kxIltBIyDmLSoLJF3UW4V16Lc5KbFOYklpx28nENlFh5fvjgnL_20g9Z9j_rTk3QAl9g7wg==

Users on the official website[3] can access detailed coastal information for a specific location through a map's popup view. Within this popup, multiple tabs are available, allowing viewers to navigate through them to find various details related to the coastal area. This interactive feature enables users to explore comprehensive information about the chosen coastal location.

In today's digital world, the visualization of geographic locations often misses out capturing the full picture, especially when it comes to the vertical context of geographic locations. In the DBpedia context, a significant challenge arises from information overload, making it difficult for users to efficiently locate their desired information. While all vertical attributes are consolidated on a single webpage, the sheer volume necessitates extensive scrolling. The lack of grouping for attributes adds to the complexity, as they are not presented in a structured manner. Additionally, the use of hyperlinks for certain attributes further complicates the visual identification of vertical attributes. This lack of organization and clarity may impede users from swiftly finding and accessing specific details, thus affecting the overall user experience. In the contrast, Umweltbundesamt faces challenges in its effectiveness due to the fragmented presentation of vertical attributes dispersed across various interfaces rather than being consolidated in a single window. The absence of an option to view all air pollutant values in one window requires users to filter multiple times, resulting in a repeating process. Consequently, users are unable to obtain a comprehensive overview of air quality indices and air pollution for a location in a unified window. This limitation hinders the user's ability to easily grasp the complete picture of the air quality scenario in a particular area. Similarly, the “Arctic Coastal Dynamics” employs a tab-based navigation system within popups. However, constantly switching between tabs to access data for different attributes can disrupt the user's flow, potentially resulting in a less cohesive understanding of the vertical aspects.

[3] https://maps.awi.de/awimaps/projects/public/?cu=arctic_coastal_dynamics#home

1.2 Research Gap

Current geographic visualizations often fall short in capturing the complete picture, particularly in representing vertical context of Geographic locations. To overcome this issue, it is suggested to adopt a more integrated approach, presenting all vertical attributes in a consolidated view. Enhancing the user interface and employing improved visualization techniques are proposed solutions to optimize the exploration of vertical context in geographic locations.

Innovations in visualization techniques are essential to bridge challenges and offer users a seamless exploration experience, providing a comprehensive understanding of a location's vertical context without the need for constant navigation and filtering adjustments. This is especially important in various fields. As the examples, "Umweltbundesamt" offers crucial air quality data, while "Arctic Coastal Dynamics" provides valuable information on Arctic coastal dynamics. Similarly, in general data exploration, DBpedia plays a significant role.

1.3 Research Objectives

This research addresses the question: “How to effectively visualize the vertical context of geographic locations?”.

The research aims to solve the problem of effectively visualizing the vertical attributes of geographical location on maps with maintaining a more accurate, complete, and user-friendly visualization for vertical context of geographical locations, offering insights that might be overlooked in conventional two-dimensional representations.

1.4 Innovation

This study tries to create a new web application with enhancing the visualization techniques to overcome the challenges associated with representing vertical context in a single window. Such an approach can bring several advantages. Consolidating all vertical attributes into a single window allows users to navigate and explore information seamlessly, eliminating the need for extensive scrolling, continuous filtering, or tab-switching. This innovation not only save users time and energy but also enhance the user-friendly experience. Moreover, it increases the likelihood of capturing the full picture of a geographic location by offering a comprehensive understanding of its attributes.

1.5 General method

The method used in this work was comprised of the following steps:

- Reviewing existing literature extensively to understand the current state of knowledge on the topic.
- Selection of data sets to visualize vertical context of geographic locations and acquiring the data using APIs.

1. DBpedia[4] (vertical context of general details for geographic locations)
2. Umweltbundesamt[5] (vertical context of air quality data for German cities)

- Identification of functional and non-functional requirements for web application.
- Selection of geographic locations and attributes to visualize vertical context of geographic locations.
- Data cleaning and processing data to JSON file format.
- Development of prototype that incorporates three distinct visualization approaches, each aligned with different navigation behaviors to visualize vertical context of geographic locations:

1. Scrolling baseline approach (Categorization + Scrolling):

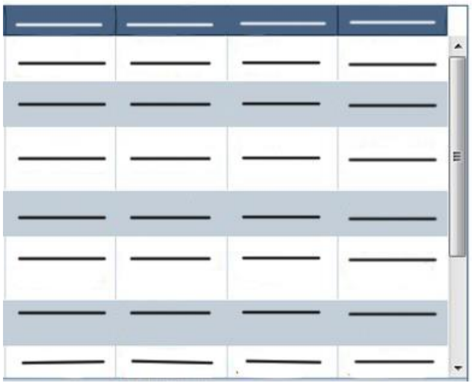

Figure 1: Scrolling baseline approach

The attribute data is structured in a table format (Figure 1), with distinct columns such as index, name, value, and group, serving to segregate the characteristics of attribute details. Each row corresponds to a different vertical attribute, presenting a systematic arrangement. In cases where there are numerous vertical attributes, a scroll bar is provided for seamless navigation, allowing users to scroll vertically through the attributes from top to bottom or vice versa.

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[4] https://www.dbpedia.org/resources/live/dbpedia-live-sync/
[5] https://www.umweltbundesamt.de/daten/luft/luftdaten/doc#

Notably, attributes belonging to the same category are consecutively placed in rows, resulting in a linear distribution.

The table format is designed using the Bootstrap CSS framework and data is injected using a standard JavaScript program. Bootstrap provides a responsive and visually appealing structure to the table, enhancing its design and functionality.

2. Spiral-type leaflet markers approach (Categorization + Semantic panning):

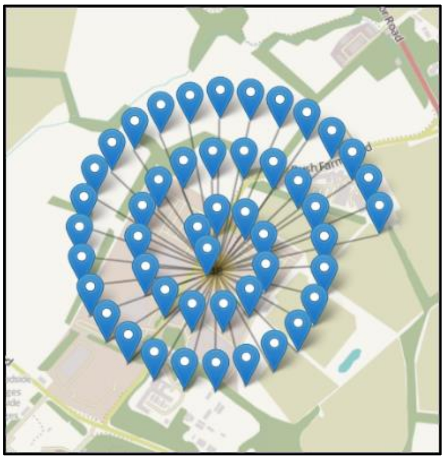

Figure 2: Spiral-type of leaflet markers approach (Fürhoff, 2020)

The attribute data is structured into leaflet markers, forming a spiral pattern as illustrated in Figure 2 and this spiral pattern is created through a JavaScript program utilizing Leaflet.js library. Each marker represents a vertical attribute, and clicking on a marker reveals the relevant attribute name and its corresponding value in a popup. When visualizing the vertical context with numerous attributes, a spiral pattern can be arranged with high compactness. Therefore, zooming should be employed to view the attributes separately. After zooming, Mouse panning becomes a primary method for navigating from one marker to another. Additionally, center markers are situated in closer proximity than other markers, making the same mouse panning technique suitable for navigating between different attributes. Notably, markers sharing the same category are distinguished by different colors, and attributes are arranged along the outer edge of the spiral, creating a circular distribution along the arc.

3. Zoomable circle packing approach (Categorization + Semantic zooming):

In the zoomable packing visualization approach (Figure 3), vertical attributes of the same category are positioned within a single circle in close proximity and the visualization approach is implemented by utilizing the D3.js library. As users navigate through each attribute, a zooming effect is employed to facilitate a focused exploration of individual attributes, with the relevant attribute name and its corresponding value displayed in the leaf-circle. When zooming into a specific circle area, only the attributes belonging to that respective circle are shown in one window, eliminating distractions from surrounding attributes and facilitating easier identification. This zooming-out effect is also utilized when transitioning from one attribute category to another. Attributes in the same category are arranged in a clustering distribution.

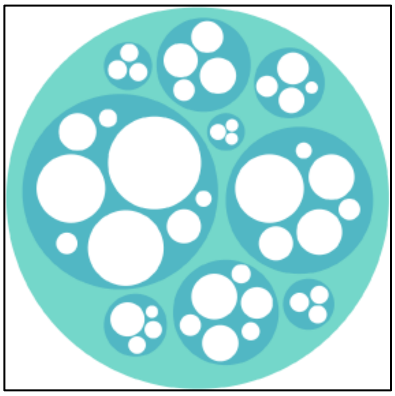

Figure 3: Zoomable circle packing approach (Bostock, 2018b)

- Experimental design and conducting the user experiment.
- Utilized the "bootES" R package to conduct statistical pairwise comparisons of the three visualization approaches.
- Evaluation the three visualization approaches based on summary of results.

1.6 Thesis Organization

The thesis comprises seven main chapters. Chapter 2 provides a review of existing works related to visualizing the vertical context of geographic locations. Chapter 3 outlines the data processing and prototype development phase. Chapter 4 focuses on the evaluation conducted for this study. Chapter 5 presents the preliminary results. Chapter 6 encompasses discussion, limitations, and future works. Lastly, Chapter 7 concludes the thesis.

2. RELATED WORKS

2.1 Visualization of Context Information

Visualization of context information is the process of representing contextual data through graphical means to facilitate comprehension and decision-making. Context information, encapsulating the surrounding circumstances, conditions, or factors pertinent to a specific situation or data point, is graphically represented to enhance accessibility and interpretability (Webster,2018). This visualization spans various contextual data types, including temporal visualization focuses on illustrating how data changes over time, capturing trends, patterns, and temporal relationships (Andrienko & Gennady Andrienko, 2006), spatial visualization involves representing data in relation to geographical locations providing insights into spatial patterns (Maceachren & Kraak, 2018), social visualization considers the display of information concerning social relationships and interactions, often utilizing network visualizations (Correa, 2011), and device and environmental contexts presents data in relation to the devices used or environmental conditions, which is particularly crucial in applications like the Internet of Things (IoT) (Heath, 2011).

In today's digital world, the internet, especially the world wide web, has become a hub for sharing maps and geospatial data. To manage large volumes of data, methods from scientific and information visualization are applied, resulting in what is referred to as geo-visualization (Kraak, 2003). To really understand and explain patterns and relationships in the geospatial context information, need to combine computer-based methods with visual approaches (Wang & Zhu, 2023). This practice employs visual displays like charts, graphs, maps, and more to explore and analyze data, helping us develop ideas and gain knowledge. Common software tools like D3.js, Tableau, and Matplotlib are used to create these visualizations (Srivastava, 2023). These visual techniques help represent numbers, geographical relationships, social connections, and event sequences (Cavaller, 2021). They allow users to interact with and explore the data dynamically. These visualizations find applications in various fields such as business intelligence, healthcare, smart cities, and scientific research. In essence, the visualization of context information aims to transform contextual data into visually comprehensible and actionable forms, facilitating effective decision-making across diverse domains through the communication of relationships and patterns within the data context (Cavaller, 2021).

2.2 Focus + Context Visualization

Information visualization is a powerful tool for simplifying complex data, offering various methods for presenting and working with different types of information. However, every information visualization method encounters a common challenge; they must fit within the limited space of a computer screen. This limitation is essential to consider when creating visualizations. To address this issue, a typical solution is to offer a movable window or viewport for the data. Users can control and navigate this view using scrollbars or other interactive tools. Another approach involves zooming interfaces, enabling users to manage the data display by zooming in or out. However, situations providing users simultaneous access to both an overview and detailed information is crucial. Sometimes, it's essential to give users both the big picture and detailed information together, achieved by having separate sections for overview and detailed data. There's a specific group of techniques aiming to blend both detailed and overall views on a single screen, preventing users from getting distracted. These methods go by various names like fisheye views, distortion-based presentations, and focus + context visualizations (Bjork et al.,1999).

The focus + context visualization has found extensive application in visualization, computer graphics, and image processing. It empowers users to seamlessly access both the broader context information and the finer details of the data. This approach ensures a comprehensive understanding by allowing users to navigate between high-level information and low-level details (Wang et al., 2011; Listemann et al., 2019)

It provides users with a focused view of specific details (focus) while maintaining a broader overview of the entire dataset (context). It aims to balance detailed information with a larger, more comprehensive perspective. Typically, focus + context visualization involves stretching or expanding part of the display to emphasize specific details (focus), while squeezing the rest to keep an eye on the bigger picture (context). Meanwhile, the remaining portion of the visualization is compressed to maintain visibility of the rest of the data, providing context and enhancing user orientation (Bonneau et al., 2006).

In the context of geographic locations, this technique is applied to enhance the visualization of spatial data, allowing users to explore specific areas in detail while retaining an understanding of the surrounding geography. This helps users maintain an understanding of the spatial relationships and context of the information. For example, when zooming in on a specific location on a map, focus + context visualization approach might involve simultaneously displaying an overview map that illustrates the entire geographical area. This allows users to navigate and explore details at the local level while retaining an understanding of the geography on a global or regional scale (Wang et al., 2011).

In the horizontal context, and vertical context of geographic locations, can be effectively achieved through focus and context visualization techniques. In this context, the horizontal context is represented by the focus, offering an intricate depiction of nearby locations, while the vertical context is embedded in the broader context, providing information about various attributes associated with the same location. By seamlessly integrating both horizontal and vertical contexts, users can gain a comprehensive understanding of the spatial relationships and attribute intricacies.

2.3 Exploratory spatial data analysis

Advancements in computing hardware and Geographic Information Science (GIS) software now allow direct interaction with large spatial databases, providing nearly instantaneous results for various GIS operations. The evolving GIS technology, with improved storage and display capabilities, has led to a demand for new tools, especially in spatial and statistical analysis (Goodchild, 1987; Goodchild et al., 1992). This arises because traditional spatial analysis techniques were found to be inadequate in tackling the challenges posed by the evolving GIS environment. Traditionally, the GIS environment presented challenges, such as dealing with vast amounts of observations and "dirty" data. Some traditional spatial analysis methods are even rejected due to statistical inference in this context (Anselin, 1996).

The emergence of exploratory spatial data analysis (ESDA) addresses these challenges. ESDA is essential for enhancing GIS analytical capabilities by adapting to the vast amount of data and unique characteristics of spatial information. Unlike traditional statistical methods, ESDA focuses on exploring and understanding the spatial aspects of the data. It aims to identify spatial properties in data, unveiling spatial patterns, formulating hypotheses related to the geography of the data, and evaluating spatial models (Haining et al.,1998; Anselin, 1996).

ESDA is like an expanded version of exploratory data analysis (EDA), specifically tailored to uncover spatial patterns in datasets. In ESDA, each attribute value is linked to a location reference, either a point or an area. In essence, it's about digging into the spatial aspects of the information to gain insights and make informed assessments (Haining et al.,1998).

ESDA has boosted by combining spatial statistics with GIS. This helps us understand events that are tied to specific locations and their spatial relationships better. In traditional terms, ESDA focuses on two spatial effects: spatial autocorrelation (or dependence) and spatial heterogeneity. Positive spatial autocorrelation means that nearby observations share similar attributes, indicating a concentration or clustering of a particular phenomenon in a specific geographic area. Spatial autocorrelation happens due to various factors. According to Tobler's 'first law of geography,' locations close to each other are more likely to have similarities than those farther apart (Dall'erba, 2009).

Moreover, ESDA techniques can be grouped into two main categories: 'global' statistics, which consider the entire map and process all cases for a specific attribute, and 'focused' or local statistics, which analyze spatially defined subsets of the data one at a time. The latter involves going through all these defined subsets to identify localized properties in the mapped data or residuals, especially after removing trends (Haining et al.,1998).

ESDA is designed to delve into spatial patterns and relationships within data, encompassing both horizontal and vertical contexts. ESDA helps uncover patterns and relationships in data across geographic space, revealing how nearby locations might exhibit similarities or differences in attributes. Vertical context in ESDA pertains to the broader context established by all available information about the same location. ESDA considers not only the immediate spatial relationships but also incorporates additional layers of information that provide a more comprehensive understanding of a specific location. This could include factors like elevation, land use, or other vertical dimensions.

3. METHODOLOGY

3.1 Web App Requirements

To develop web application for study, functional and non- functional requirements are identified.

Table 1: List of requirements for web application

The app should have a search bar with autocomplete Suggestions to search the location.	Functional
Quantity of Location markers (Geographic locations) -Top 10 populated cities in Germany	Functional
Visualizing the attributes as categories.	Functional
Number of attribute levels for visualization DBpedia – 60/ 90/ 120 UmweltBundesamt – 60/120/150/180/200	Functional
The app should have an 'About' section indicating functionalities and FAQs about the web application.	Non-Functional
The app should change the different base maps with country boundaries, labels.	Non-functional
The app should be user-friendly and have a fast-loading time. Usage of Single Page Application with popup windows.	Non-functional
The app should be responsive	Non-functional
The app should have standard CSS styles. Usage of Bootstrap CSS framework	Non-functional
The app should be available over a website	Non-functional

The application must feature a search bar equipped with autocomplete suggestions to facilitate location search. This feature streamlines the user interaction process, making it easier for users to find and navigate to specific locations of interest.

Concerning the quantity of location markers, the application should be capable of managing a specified number of geographic locations sourced from both the DBpedia and UmweltBundesamt datasets. Detailed descriptions of the DBpedia and UmweltBundesamt datasets are provided in the subsequent chapter, specifically in Subchapter 3.2. As a result, the ten most populated German cities (Berlin, Hamburg, Munich, Cologne, Frankfurt am Main, Stuttgart, Düsseldorf, Leipzig, Dortmund, Essen) have been chosen for inclusion.

To enhance efficiency and effectiveness of data visualization, attributes should be categorized into categories, making it easier for users to interpret and analyze the attributes. By organizing attributes in this manner, users can quickly identify and focus on specific aspects of interest within the data. For the DBpedia dataset, the major categories generated include Administrative, Weather, Political, and Geography. On the other hand, the major categories identified for the UmweltBundesamt datasets consist of five air pollutants: NO_2, SO_2, Fine Dust, O_3, and CO.

Furthermore, the application should be capable of visualizing different numbers of attributes for both the DBpedia and UmweltBundesamt datasets. For the DBpedia dataset and UmweltBundesamt datasets, ten selected German cities have varying attribute levels, with 60, 90, and 120 attribute levels chosen from the DBpedia dataset and 60, 120, 150, 180 and 200 attribute levels selected from the UmweltBundesamt datasets. Subsequently, the efficiency and effectiveness of each visualization approach can be assessed based on the attribute level.

The non-functional requirements for the web application encompass various aspects aimed at ensuring a seamless user experience. The inclusion of an 'About' section, outlining functionalities and frequently asked questions, contributes to user guidance and support. Emphasizing user-friendliness, the application is designed for quick and efficient use, with a priority on fast loading times. Employing a Single Page Application (SPA) with popup windows enhances navigation simplicity, while responsiveness guarantees a consistent performance across diverse devices. Adhering to standard CSS styles and incorporating the Bootstrap CSS framework ensures a visually cohesive and aesthetically pleasing interface. The web application's availability over a hosted website further facilitates convenient access for users. Together, these non-functional requirements prioritize a user-centric, efficient, and visually appealing experience.

3.2 Data Collection

To develop web application to visualize vertical context of geographic locations two primary data sources were utilized. Those are DBpedia and Umweltbundesamt.

DBpedia is a structured database derived from Wikipedia. Specifically, DBpedia provides detailed descriptions of countries, cities, landmarks worldwide. This wealth of data allows for comprehensive exploration of the vertical context of geographic locations, enabling users to understand the relevant attributes associated with a particular area. To extract relevant data from this source, "DBpedia Live Sync API" API[6] was used. For acquiring data for the selected 10 German cities from DBpedia, the DBpedia Live Sync API was utilized by inputting the city names as query parameters. The data was obtained in N-triples format.

Umweltbundesamt serves as a source for air quality data pertaining to German cities, including metrics such as Fine dust, Carbon monoxide (CO), Sulphur dioxide (SO_2), Ozone (O_3) and Nitrogen dioxide (NO_2) levels. Similarly, relevant data from Umweltbundesamt was extracted using "Air Data API (UBA) 3.0.0" API[7] was used. To acquire data for the year 2022 for the selected 10 German cities from Umweltbundesamt, substations related to each city were identified manually using the existing website provided by the Umweltbundesamt team. The Air Data API (UBA) 3.0.0 was then utilized by inputting the measuring station names as query parameters, and the data was obtained in JSON format.

3.3 Data Processing and Attribute Selection

The primary objective of the data processing phase is to make structured datasets sourced from two key data sources: DBpedia and Umweltbundesamt. Raw data extracted through pertinent APIs undergo cleaning and processing procedures during this stage. By refining the data extracted from these sources, the aim is to ensure that the resulting datasets are well-structured and without any inconsistencies or extra information. This critical processing step lays the groundwork for subsequent analyses and visualizations, enhancing the usability and reliability of the derived datasets for further exploration and interpretation. Two distinct data processing methods are illustrated in Figures 4 and 5 for handling data extracted from the primary data sources.

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[6] https://www.dbpedia.org/resources/live/dbpedia-live-sync/
[7] https://www.umweltbundesamt.de/daten/luft/luftdaten/doc

3.3.1 Data processing for data from DBpedia

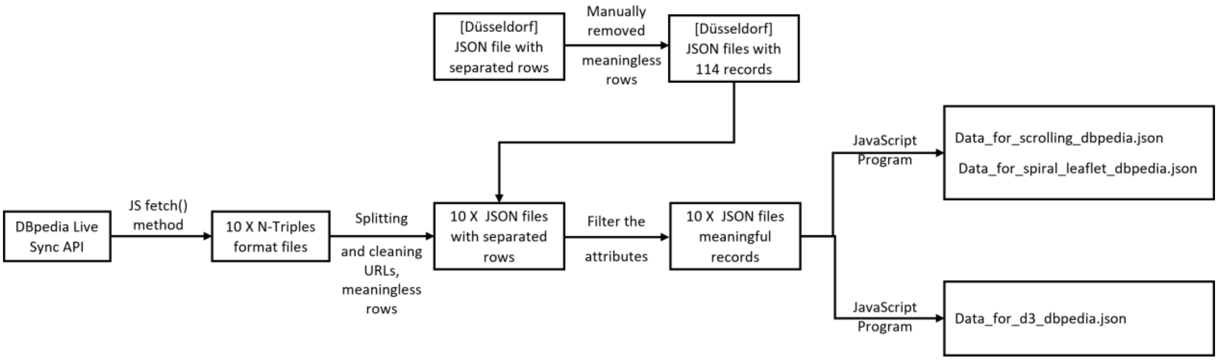


Figure 4: Data processing work flow for DBpedia dataset

Data acquisition from the "DBpedia Live Sync API" involved querying the platform with the names of ten selected German cities, retrieving data in N-triples format using JavaScript's fetch method.

Following retrieval, the ten JSON files undergo preprocessing steps, including splitting and removal of URLs and meaningless rows. Subsequently, ten JSON files were generated, each containing structured data specific to one of the ten cities with semi-meaningful values. The number of records in each JSON file was counted. Düsseldorf had a medium value of attributes. Hence, the JSON file related to the city of Düsseldorf was selected and manually processed to remove meaningless records. This JSON file comprises 114 meaningful records after the manual removal of extraneous rows. Next, this Düsseldorf file was used as a mask to filter the same attributes in the other nine JSON files using JavaScript program.

Afterward, total ten JSON files served as the foundation for creating three distinct JSON files tailored for various visualization techniques: scrolling, spiral-type leaflet markers, and zoomable circle packing. Notably, while the JSON structure remained consistent for scrolling and spiral-type leaflet markers visualization approaches, data arrangement for zoomable circle packing visualization adhered to specific requirements (data as children and parents) dictated by D3.js documentation.

3.3.2 Data processing for data from Umweltbundesamt

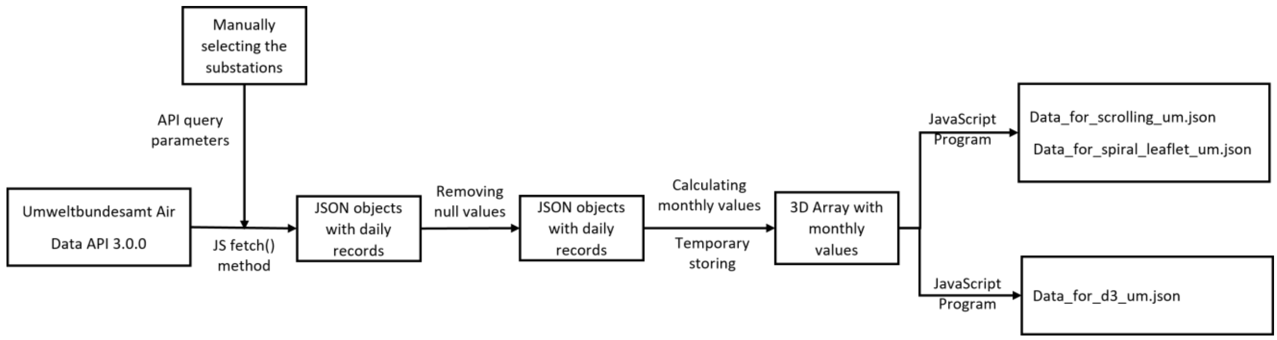


Figure 5: Data processing work flow for Umweltbundesamt dataset

To gather data for the year 2022 to the selected 10 German cities from Umweltbundesamt, the first step involved manually identifying substations associated with each city through the Umweltbundesamt website. Once the relevant measuring station names were determined, the Air Data API (UBA) 3.0.0 was leveraged, with the station names serving as query parameters using the JavaScript fetch method. This facilitated the retrieval of data in JSON object containing daily records were acquired for each of the ten cities. Null values were then eliminated, and monthly average, maximum values were computed based on the daily readings. These monthly average and maximum values were organized and stored as a 3D array.

Finally, utilizing structured JavaScript programming, ten JSON files were generated, each tailored to a specific visualization approach and formatted according to the requirements of the respective method. This process ensured that the extracted data was refined, organized, for seamless integration into visualization frameworks.

Table 2 presents a detailed summary of the generated attribute count for each city across two datasets. This summary includes information on the levels of attributes (60, 90, 120, 150, 180, and 200) corresponding to each dataset.

Table 2: Summary of generated attributes

City	DBpedia dataset		Umweltbundesamt dataset	
	Attribute count	Attribute level	Attribute count	Level of attributes
Berlin	103	90	192	180
Hamburg	110	120	204	200
Munich	113	120	168	150
Cologne	112	120	204	200
Frankfurt am Main	114	120	204	200
Stuttgart	113	120	144	150
Düsseldorf	115	120	60	60
Leipzig	108	120	108	120
Dortmund	64	60	60	60
Essen	90	90	120	120

3.4 Development of Web Application

3.4.1 Web app Architecture

In the web app architecture (Figure 6), the three main sections are the user/client interface, application logic, and data management. Each section plays a crucial role in delivering a seamless and interactive experience to users.

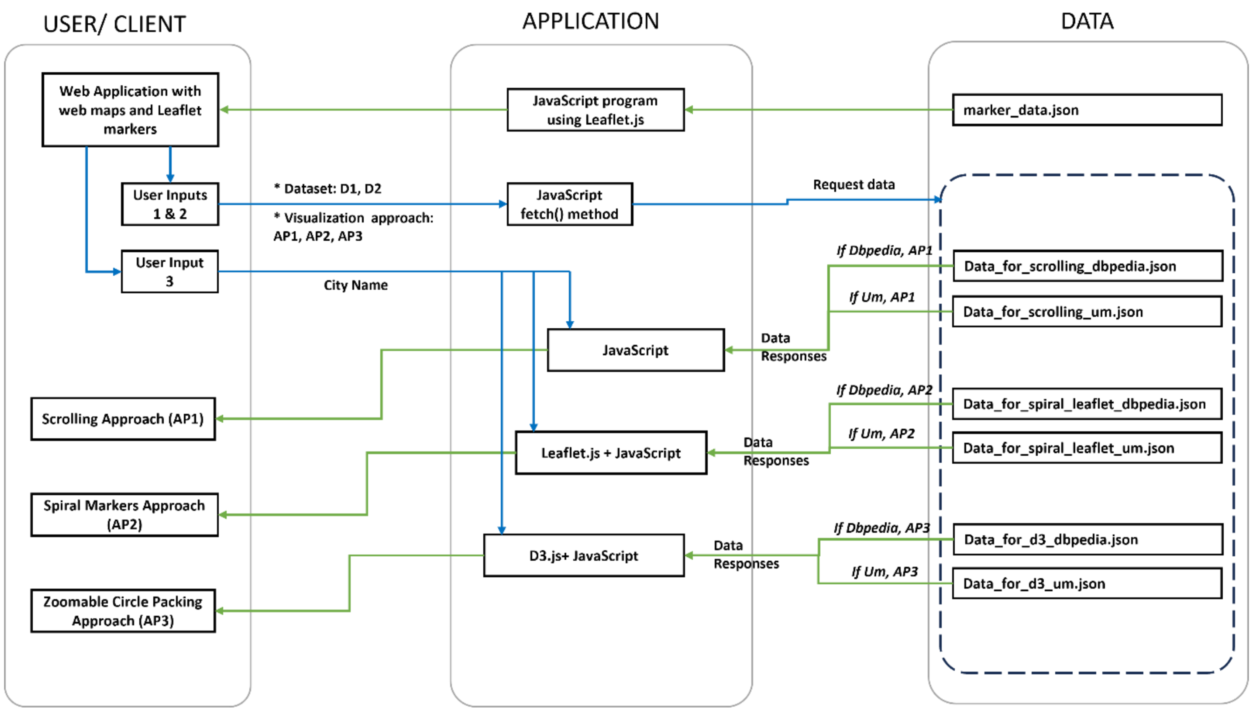


Figure 6: Web App architecture

1. **User/Client Interface:** This section represents the user interface, serving as the platform for users to engage with the web application. It encompasses various

components, such as background Web Map Tile Service (WMTS) base maps, location markers, a search bar, navigation bar, popups, and visualizations presented to the user. Within this interface, users provide their preferences and selections, offering guidance to the application on how to process and display data. Figure 7 provides a visual representation of the user interface, highlighting key elements within the graphical user interface (GUI).

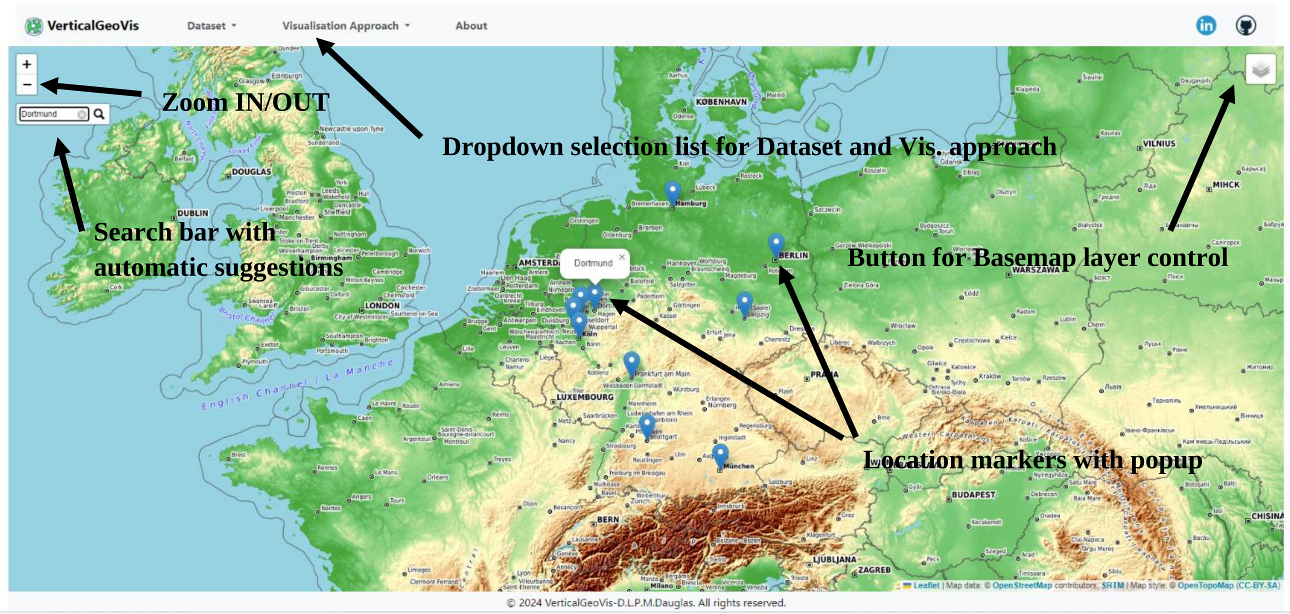


Figure 7: User interface and the main elements in the GUI.

2. **Application Logic:** The application logic encompasses the front-end processes responsible for interpreting user inputs, fetching relevant data, and generating visualizations based on those inputs. It acts as the intermediary between the user interface and the data management section, orchestrating the flow of information and actions within the application.

To add base maps and location markers, the Leaflet.js version 1.9.4 was used, employing a spiral-type Leaflet marker approach. For interactions in the Zoomable Circle Packing approach, D3.js Version 4 was utilized. Regarding CSS styles, Bootstrap version 5.3.2 served as the CSS framework.

3. **Data Management:** In this section, the focus is on handling and processed data required for visualization. In Sections 3.3.1 and 3.3.2, the procedures for processing data from two datasets are outlined. A total of six JSON files, generated as outputs in the data processing

stage, were used along with an additional JSON file containing location data for markers corresponding to 10 cities.

When a user interacts with the web app, the application responds based on the user's inputs: User Requests Data Set and Visualization Approach: If the user selects a specific data set (e.g., DBpedia or Umweltbundesamt) and a visualization approach (e.g., Visualization Approach 1, Visualization Approach 2 or Visualization Approach 3), the application retrieves the relevant data and visualization method based on the user-selected city.

3.4.2 Visualization Approaches

Link to the designed web application **VerticalGeoVis** - https://prasadmadhusanka.github.io/VerticalGeoVis/#

- **Visualization Approach 1 (Scrolling baseline approach):**
  Figure 8 illustrates a categorization system and scrolling technique to showcase data from the Umweltbundesamt dataset related to Berlin. The information is presented in a table format, categorized by main attribute category.

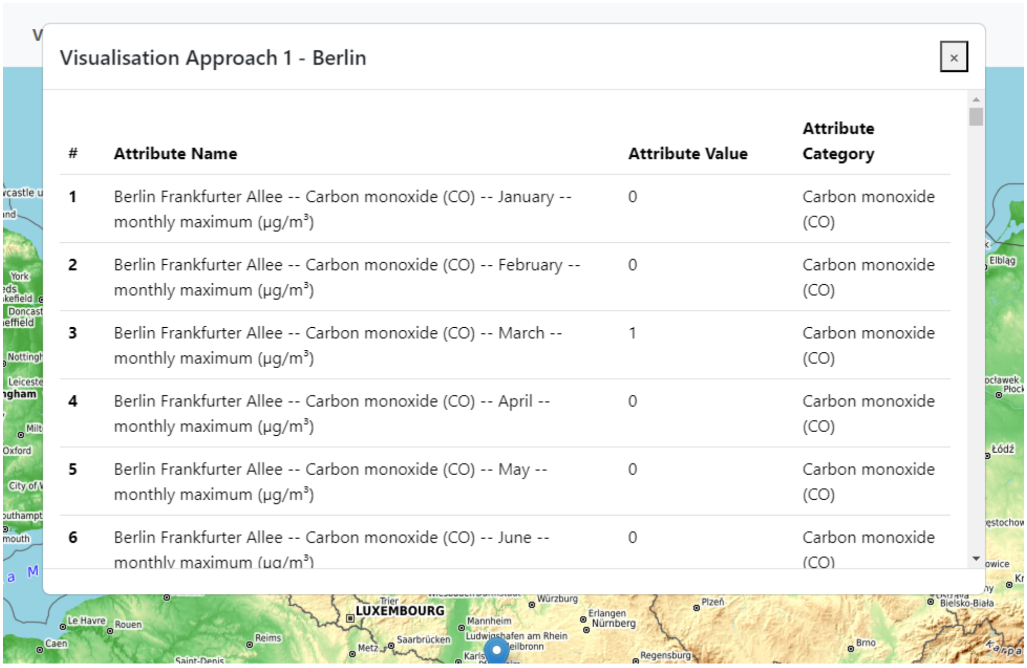


Figure 8: Scrolling baseline approach for Berlin city using the Umweltbundesamt dataset

Each attribute is assigned an index and sorted based on its relevant attribute category. This arrangement enables users to efficiently search for specific data by scrolling through the table. Categorizing the data facilitates swift navigation to sections of interest, enhancing the overall efficiency of data retrieval. Additionally, the attribute indexing improves the ease of counting the attributes relevant to each group or attributes within the dataset.

- **Visualization Approach 2 (Spiral-type Leaflet markers approach):**
  Figure 9 shows the view of Visualization approach 2 related to Hamburg from the Umweltbundesamt dataset using categorization and a panning effect. Instead of a traditional table format, the data is represented by leaflet markers arranged in a spiral pattern. Each marker represents different attributes, making it easy for users to identify and differentiate between them.

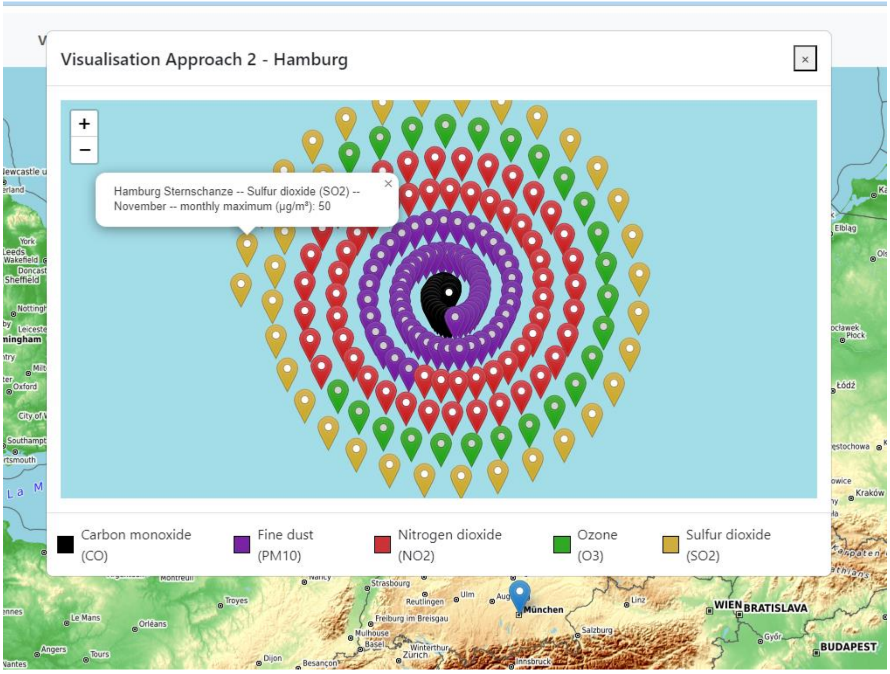


Figure 9: Spiral-type leaflet markers approach for Hamburg city using the Umweltbundesamt dataset

When users click on a marker, a pop-up message appears, showing the name of the attribute category and its corresponding values. This feature enhances user interaction by providing instant access to relevant information in a visually appealing way. When visualizing the vertical context with numerous attributes, a spiral pattern can be arranged with high compactness. Therefore, zooming should be employed to view the attributes separately. After zooming, Mouse panning becomes a primary method for navigating from one marker to another. Additionally, center markers are situated in closer proximity than other markers, making the same zoom and mouse panning technique suitable for navigating between different attributes. For example (Figure 10), if someone wants to find Carbon monoxide details (black color markers) about Hamburg, they can pan through the spiral pattern to locate the marker representing Carbon monoxide attributes. Upon clicking the marker, the pop-up message will display the relevant Carbon monoxide information.

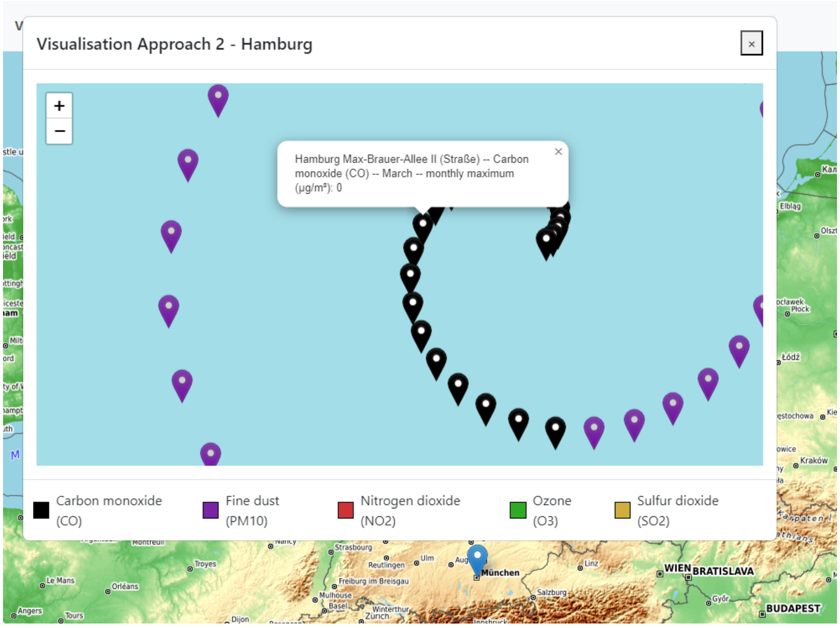
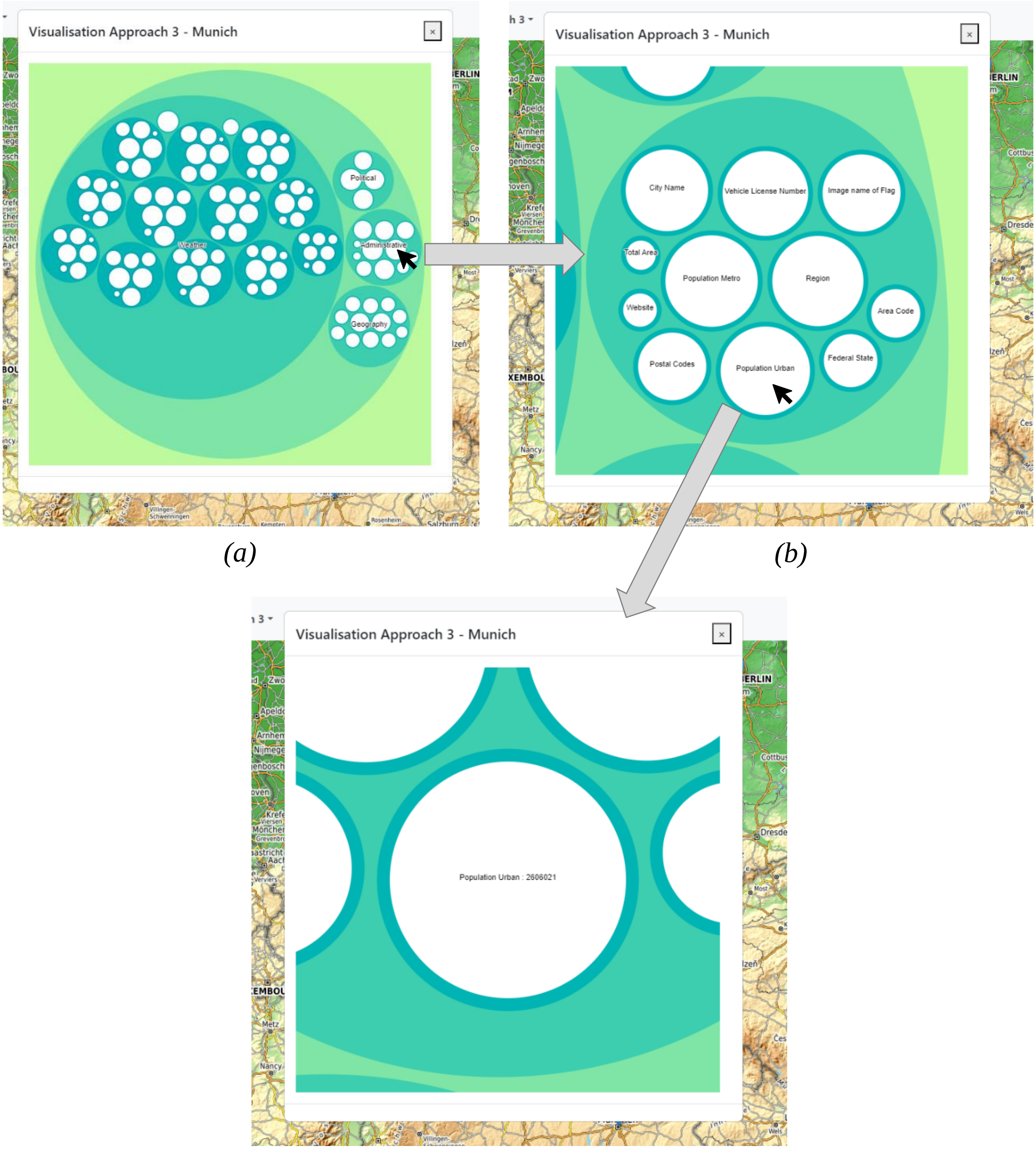


Figure 10: View of Spiral-type Leaflet markers approach for centered markers after zooming

- **Visualization Approach 3 (Zoomable circle packing approach):**

  Visualization approach 3, as depicted in Figure 11-a and implemented using D3.js version 4 with data from the DBpedia dataset, organizes information into circles representing distinct attribute categories related to Munich. Upon a user's click on a category, the visualization seamlessly zooms in to display that specific circle (Figure 11-b). In this focused view, only attributes belonging to the selected category are presented, eliminating distractions from surrounding attributes and streamlining identification. Further interaction allows users to click on leaf-circles containing attribute names, revealing attribute values (Figure 11-c).

  The zooming-out effect is intelligently applied during transitions between attribute categories, simplifying the exploration process for users. This automated zooming mechanism enriches the user experience by directing their attention to the chosen category effortlessly, requiring no additional manual navigation. Ultimately, the design promotes efficient data exploration, enhancing user engagement and comprehension.



(a) *(b)* *(c)*

Figure 11: Zoomable circle packing approach for Munich city using the DBpedia dataset

4. EVALUTION

4.1 Goal of Experiment

The goal of the experiment was to compare the scrolling baseline approach, spiral-type leaflet markers approach and zoomable circle packing approach to represent the vertical context of geographic location. Through user experiment and quantitative metrics such as efficiency, effectiveness, enjoyment, usefulness, satisfaction, and ease of use were identified for three visualization approach and informing the strengths and weaknesses of visualization approaches. Ultimately identify the special features of best visualization technique among Categorization + Scrolling, Categorization + Semantic panning and Categorization + Semantic zooming functionalities for representing the vertical context of geographic locations.

4.2 Hypothesis

Based on my previous experience and my opinion, three hypothesis were listed as follows.

- H1 - The zoomable circle packing approach will be the best visualization method for deeper understanding the vertical context of geographic locations with 60, 90, 120, 150, 180, 200 attributes. The spiral-type leaflet markers approach and the scrolling baseline approach will be ranked as 2^{nd} and 3^{rd}, respectively.
- H2 - The zoomable circle packing approach will be the best visualization method for determining the number of attributes belonging to each attribute category.
- H3 - The spiral-type leaflet markers approach will be better than the other two visualization approaches for determining the number of main attribute categories.

4.3 Variables

The following variables were considered for the user experiment.

- Independent variables: Scrolling baseline approach (Categorization + scrolling), Spiral-type leaflet markers approach (Categorization + semantic panning), Zoomable circle packing approach (Categorization + semantic zooming)
- Dependent variables: efficiency (task completion time), effectiveness (accuracy of tasks), user satisfaction (enjoyment, usefulness, satisfaction, ease of use) of visualization approach
- Controlled variables: range of screen size and number of screens used, initial training.

- Subject: age, gender, educational background, English proficiency, computer literacy and prior experience with visualization tools (regarding web maps, Leaflet.js markers and D3.js zoomable circle packing).

4.4 Experiment Design

4.4.1 Randomization

This experiment followed a within-group design. That means that each participant in the study would be exposed to all three visualization approaches at three different times, instead of having separate group of participants assigned to each visualization approach which would be a between-groups design.

The method for maintaining the randomization for independent variables is extensively discussed and written as follows (Table 3). It helps to distribute potential bias evenly across experimental groups.

- SCR - Scrolling baseline approach
- SPI - Spiral-type leaflet markers approach
- ZOM - Zoomable circle packing approach
- D1 - Dbpedia dataset
- D2 - UmweltBundesamt dataset
- P – Participant

In this experiment there were six different experimental groups (Group 1 to Group 6) and each consisting of three members. Therefore total 18 participants (P1 to P18) were selected for the experiment. Members within the same group dealt with tasks generated by the same dataset, while adjacent group members dealt with tasks generated by another dataset. For example members of Group 1 dealt with tasks related to Dbpedia dataset (D1) and members of Group 2 deal with tasks related to UmweltBundesamt dataset (D2). Here, T1 to T6 are tasks generated by six different cities, considering various attribute levels (60, 120, 90, 200, 180, 150). For example, T1 was designed by considering 60 vertical attributes in Dortmund city, and T2 was designed by considering 120 attributes in Düsseldorf city. These tasks are detailed in Section 4.4.2.

Table 3: Randomization pattern for visualization approaches

Group	Participant ID	C1	C2	C3	Dataset
Group 1	P1	SCR (T_1)	SPI (T_2)	ZOM (T_3)	D1
Group 2	P2	SPI (T_4)	ZOM (T_5)	SCR (T_6)	D2
Group 3	P3	ZOM (T_2)	SCR (T_3)	SPI (T_1)	D1
Group 4	P4	SCR (T_5)	SPI (T_6)	ZOM (T_4)	D2
Group 5	P5	SPI (T_3)	ZOM (T_1)	SCR (T_2)	D1
Group 6	P6	ZOM (T_6)	SCR (T_4)	SPI (T_5)	D2
Group 1	P7	SCR (T_1)	SPI (T_2)	ZOM (T_3)	D1
Group 2	P8	SPI (T_4)	ZOM (T_5)	SCR (T_6)	D2
Group 3	P9	ZOM (T_2)	SCR (T_3)	SPI (T_1)	D1
Group 4	P10	SCR (T_5)	SPI (T_6)	ZOM (T_4)	D2
Group 5	P11	SPI (T_3)	ZOM (T_1)	SCR (T_2)	D1
Group 6	P12	ZOM (T_6)	SCR (T_4)	SPI (T_5)	D2
Group 1	P13	SCR (T_1)	SPI (T_2)	ZOM (T_3)	D1
Group 2	P14	SPI (T_4)	ZOM (T_5)	SCR (T_6)	D2
Group 3	P15	ZOM (T_2)	SCR (T_3)	SPI (T_1)	D1
Group 4	P16	SCR (T_5)	SPI (T_6)	ZOM (T_4)	D2
Group 5	P17	SPI (T_3)	ZOM (T_1)	SCR (T_2)	D1
Group 6	P18	ZOM (T_6)	SCR (T_4)	SPI (T_5)	D2

For each visualization approach, 18 data points were collected, resulting in a total of 54 data points. Summary of expected data points is shown in Table 4 and Table 5.

Table 4: Expected data points for each visualization approaches

	SCR	SPI	ZOM	Total
Data points	18	18	18	54

When considering a total of 54 data points, nine points correspond to sixty attributes level, and an additional nine points are allocated for each subsequent increment of thirty attributes, such as 90, 120, 150, 180, and 200 and so on.

Table 5: Expected data points with respect to the attribute levels

	Attribute level						
	60	90	120	150	180	200	Total
Data points	9	9	9	9	9	9	54

4.4.2 Generated tasks for users

These tasks (T1 to T6), along with the questions and the order of questions in each task, were designed to accommodate three visualization approaches without bias. Each task consists of a total of five questions. The fourth question was specially designed to check hypothesis H2, and the fifth question was designed to check hypothesis H3. T1 was designed for the 60 vertical attribute level in Dortmund City, T2 for the 120 vertical attribute level in Düsseldorf City, T3 for the 90 vertical attribute level in Essen City, T4 for the 200 vertical attribute level in Hamburg City, T5 for the 180 vertical attribute level in Berlin City, and T6 for the 150 vertical attribute level in Munich City.

Task (T1) is described as follows. (Dortmund-60 attributes)

- q1: What is the low temperature in Dortmund for September?.
- q2: What is the recorded high temperature in Dortmund for May?.
- q3: Who is the leader of Dortmund (Leader Name)?.
- q4: How many attributes belong to the 'Weather' category?.
- q5: What are the attribute categories for Dortmund that you can access through this approach?.

Task (T2) is described as follows. (Düsseldorf-120 attributes)

- q1: What is the low temperature in Düsseldorf for September?.
- q2: What is the recorded high temperature in Düsseldorf for May?.
- q3: Who is the leader of Düsseldorf (Leader Name)?.
- q4: How many attributes belong to the 'Weather' category?.
- q5: What are the attribute categories for Düsseldorf that you can access through this approach?.

Task (T3) is described as follows. (Essen-90 attributes)

- q1: What is the low temperature in Essen for September?.
- q2: What is the recorded high temperature in Essen for May?.
- q3: Who is the leader of Essen (Leader Name)?.
- q4: How many attributes belong to the 'Weather' category?.
- q5: What are the attribute categories for Essen that you can access through this approach?.

Task (T4) is described as follows. (Hamburg-200 attributes)

- q1: What is the monthly maximum (μg/m^3) of "Ozone (O3)" recorded in the "Hamburg Sternschanze" station for April?.
- q2: What is the monthly maximum (μg/m^3) of "Nitrogen dioxide (NO2)" recorded in the "Hamburg Max-Brauer-Allee II (Straße)" station for October?.
- q3: What is the monthly average (μg/m^3) of "Fine dust (PM10)" recorded in the "Hamburg Habichtstrasse" station for December?.
- q4: How many data records (vertical attributes) are available for the air pollutant "Fine dust (PM10)"?.
- q5: What are the categories of air pollutants that exist in Hamburg city?.

Task (T5) is described as follows. (Berlin-180 attributes)

- q1: What is the monthly maximum (μg/m^3) of "Ozone (O3)" recorded in the "Berlin Friedrichshagen" station for April?.
- q2: What is the monthly maximum (μg/m^3) of "Nitrogen dioxide (NO2)" recorded in the " Berlin Wedding" station for October?.
- q3: What is the monthly average (μg/m^3) of "Fine dust (PM10)" recorded in the "Berlin Schildhornstraße" station for December?.
- q4: How many data records (vertical attributes) are available for the air pollutant "Fine dust (PM10)"?.
- q5: What are the categories of air pollutants that exist in Berlin city?.

Task (T6) is described as follows. (Munich-150 attributes)

- q1: What is the monthly maximum (μg/m^3) of "Ozone (O3)" recorded in the "Munich/Johanneskirchen" station for April?.
- q2: What is the monthly maximum (μg/m^3) of "Nitrogen dioxide (NO2)" recorded in the "Munich/Lothstrasse" station for October?.
- q3: What is the monthly average (μg/m^3) of "Fine dust (PM10)" recorded in the "Munich/Stachus" station for December?.
- q4: How many data records (vertical attributes) are available for the air pollutant "Fine dust (PM10)"?.
- q5: What are the categories of air pollutants that exist in Munich city?.

4.4.3 Experiment materials and procedure of the experiment

For user experiment participants connected through the Google Meet platform according to the provided time schedule. The whole experimental session for one participant was scheduled to last approximately 40 minutes and it was conducted with one participant and one examiner present. The procedure started with a clear explanation of the experiment's goals. Participants were asked to provide a video consent through Google Meet as an alternative to sign the consent form or send the signed consent from through email, ensuring their voluntary agreement to participate. After that, participants were asked to provide background information. Within this section, participants provided answers for personal details, computer literacy, and familiarity with web maps, Leaflet.js marker patterns, and D3.js zoomable circle-packing visualization approach.

Once the background questionnaire session is completed, participants proceeded to perform the designated tasks (three tasks) using prototype. Questions of each task are mentioned in section 4.4.2. The examiner only observed the entire process. During each task, participants were asked to answer five questions. The whole questionnaire developed by the LimeSurvey platform and it was utilized to record the duration required by participants to respond to designated questions. Upon completion of each task, participants were asked to answer one question related to measuring the enjoyment of visualization approach (Saket et al., 2016) and three questions from USE questionnaire to measure usefulness, satisfaction, ease of use of visualization approach using a 7-point Likert scale (quest.cgi, 2019).

To conclude the experimental session, participants were asked to respond to three questions. The first two mandatory questions were: "Considering the three visualization approaches you've interacted with, could you please rank them in order of preference based on which one you found most effective in helping you answer the questions?" and "Could you please provide reasons for ranking them?" Finally, the examiner offered participants the opportunity to give comments and suggestions regarding this Web Application for further improvements. The materials for the experiment, designed using LimeSurvey, are provided in Annexure I.

Procedure for the experiment for one participant is illustrated in Figure 12.

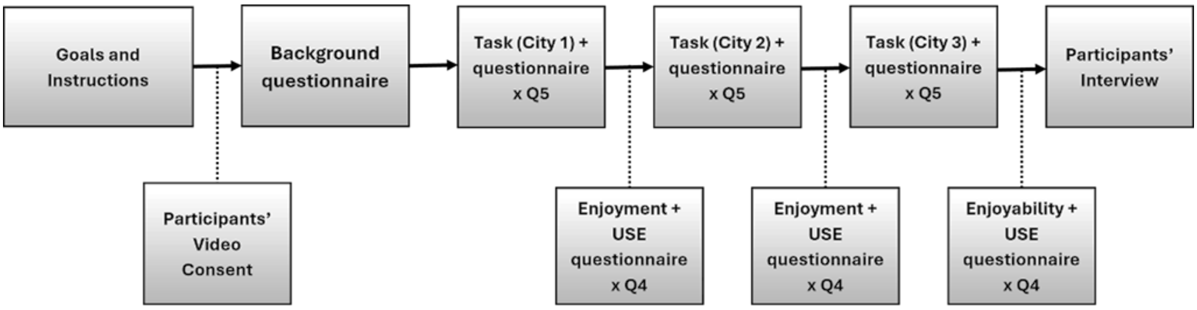


Figure 11: Workflow of the experiment for one participant

The only infrastructure needed was the laptop or desktop computer (screen size between 13 inches to 27 inches) without any additional monitors. Good internet connection was required.

Prior to the main study, a pilot test was conducted for two participants to ensure the validity and reliability of the experimental materials and procedures. This pilot test and main survey underwent and received approval from the institutional ethics board of Institute for Geoinformatics, University of Münster.

4.5 Participants

This study involving 18 participants, comprising (6/18) females and (12/18) males, the age distribution varied: (12/18) participants fell within the age range of 21 to 30 years, while (4/18) participants were aged between 31 and 40. Additionally, there was (1/18) participant each in the age groups of 41-50 and 51-60. Notably, all participants utilized their personal laptops with one screen to complete the survey, highlighting the consistency in the technological environment across the study.

Regarding computer literacy, the participants demonstrated varying levels of proficiency, with (2/18) participants classified as beginners, (7/18) as intermediate, and (9/18) as advanced users. Similarly, the familiarity with Leaflet.js markers and D3 zoomable circle packing also exhibited a range of expertise among the participants. Specifically, (1/ 18) participants were highly familiar with Leaflet.js marker patterns, while (8/18) participants reported moderate familiarity, and (9/18) participants indicated a lack of familiarity. The familiarity distribution was similar for D3.js zoomable circle packing, further indicating a diverse range of expertise levels within the participant pool.

Overall, the study encompassed a diverse group of participants in terms of gender, age, and technological proficiency, offering valuable insights into their collective experience and expertise levels related to computer literacy and familiarity with specific technologies such as Leaflet.js and D3.js zoomable circle packing.

5. RESULTS

The R package bootES ("bootstrap Effect Sizes") (Daniel & Gerlanc, 2023) was used for the analysis and it was used the 'boot' package to find the bootstrap confidence intervals for both original scale (unstandardized) and normalized across different scales (standardized) effect-size measures appropriate for experimental and survey research. These include effect sizes for mean, mean differences, contrasts, correlations, and differences between correlations. By comparing the bootstrap confidence intervals with the value of the dependent variable alone, statistical significance can be observed easily.

The next sub sections present the results of the pairwise comparison of the three visualization approaches. The following applies to all tables. The first two columns of the result tables represent the two visualization approaches being compared. Third column represent the mean value difference of two groups $(\text{Mean}_{\text{Group 2}} - \text{Mean}_{\text{Group 1}})$. Positive values for both the lower and upper confidence interval bounds (CI_{Low} and CI_{High} values) suggest that the visualization in the second column produced significantly higher values than the one in the first column. Conversely, negative values for both CI_{Low} and CI_{High} indicate that the visualization in the first column resulted in significantly higher values than the one in the second column. A statistically significant difference between the two groups is implied when the upper bounds of the bootstrap confidence interval do not enclose zero (Gorte & Degbelo, 2022).

Statistically significant differences between the two groups are highlighted in the tables with light yellow colored background. The bias is the difference between the mean of the resamples and the mean of the original sample. The SE (standard error) is the standard deviation of the resampled means (Kirby & Gerlanc, 2013). The number of resamples used in the analysis was N=5000.

5.1 Efficiency

5.1.1 Overall efficiency

In each task, there were five questions, and the time taken for each question was measured. Overall efficiency was computed by averaging the time taken for each question in the task. Table 6 presents the efficiency results.

Table 6: Bootstrapping results: Influence of the visualization approach on the time needed to solve tasks at different vertical attribute levels.

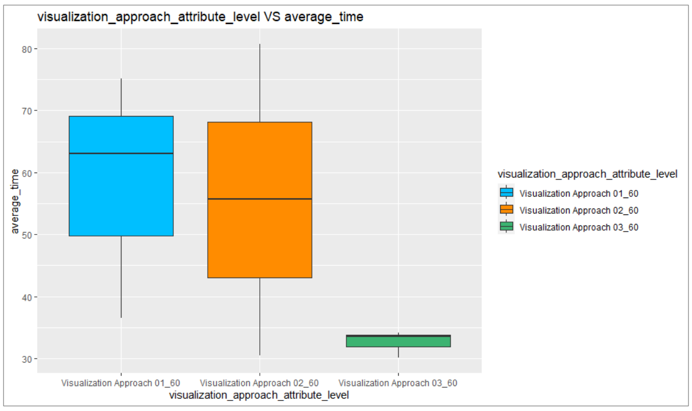
Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference (Seconds)	CI $_{Low}$	CI $_{High}$	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	-2.683	-32.290	26.923	-0.275	15.067
		90	-1.410	-16.817	16.890	0.083	8.646
		120	38.620	14.347	60.617	-0.150	11.927
		150	0.540	-24.970	33.817	0.033	14.921
		180	-26.213	-68.587	3.677	0.160	18.006
		200	53.187	-15.663	94.673	-0.498	26.722
		Overall	10.340	-6.866	30.913	0.127	9.597
Scrolling Baseline Approach	Zoomable circle packing Approach	60	-25.693	-41.287	-3.977	-0.024	9.332
		90	12.727	-4.870	28.067	-0.003	8.478
		120	45.377	35.303	55.667	-0.098	5.254
		150	6.237	-25.670	38.143	0.269	16.996
		180	-32.430	-79.430	0.807	-0.282	19.493
		200	-8.323	-22.683	6.557	-0.053	7.507
		Overall	-0.351	-15.972	13.251	0.010	7.410
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	-23.010	-48.077	0.813	0.314	11.687
		90	14.137	-10.537	32.650	-0.050	11.261
		120	6.757	-19.130	29.887	-0.162	12.645
		150	5.697	-25.023	23.963	0.066	11.312
		180	-6.217	-35.967	12.427	0.119	12.117
		200	-61.510	-103.397	1.197	-0.116	26.842
		Overall	-10.691	-31.810	4.440	0.064	9.115

The key takeaways are:

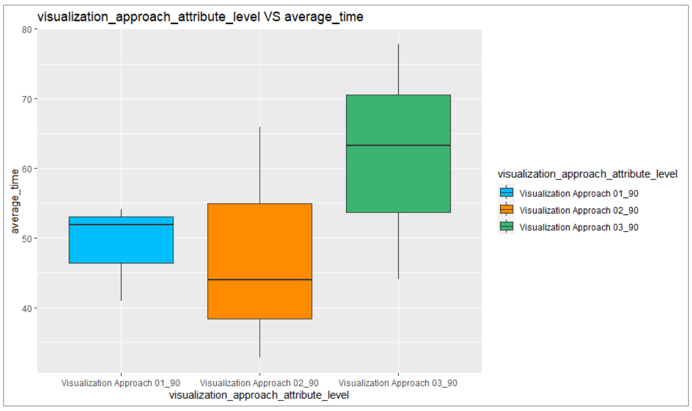
- Scrolling baseline approach vs Spiral-type leaflet markers approach: Each visualization approach had a slight advantage for 60, 90, 150, 180, and 200 vertical attribute levels, but the advantages were not statistically significant. At the 120 vertical attribute level, the scrolling baseline approach had a statistically significant advantage over the spiral-type leaflet markers approach because Participant 07 took more time to complete the task related to spiral-type Leaflet markers.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach was significantly faster at the 60 vertical attribute level. The scrolling baseline approach was significantly faster at the 120 vertical attribute level because Participant 03 took more time on q4 related to the scrolling baseline approach and Participant 15 took more time on q5 related to the zoomable circle packing approach.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: Each visualization approach had a slight advantage for some vertical attribute levels, but the advantages were not statistically significant.

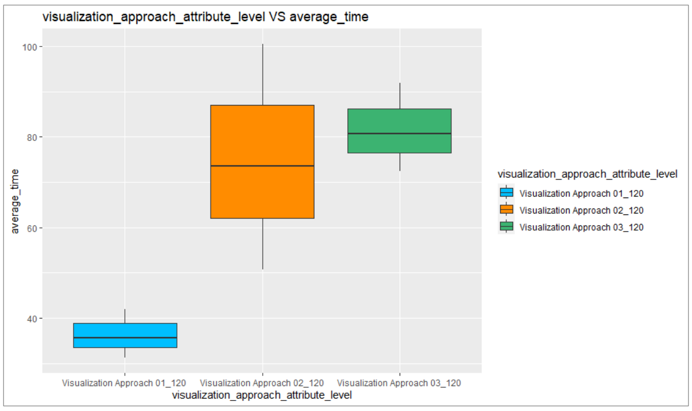
Figure 13 illustrates the graphical representation of overall efficiency of each visualization approaches at different vertical attribute levels.



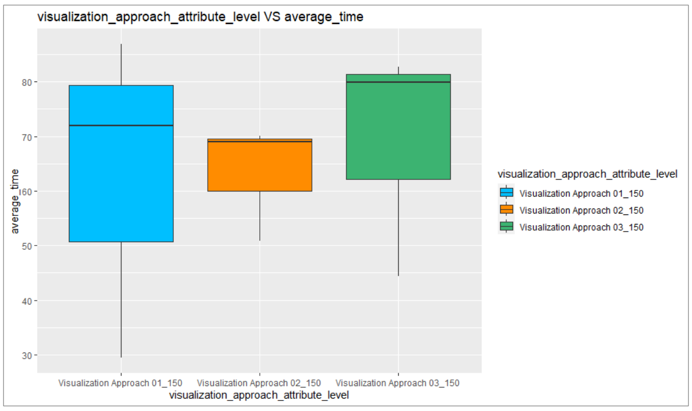
(a) 60 vertical attribute level



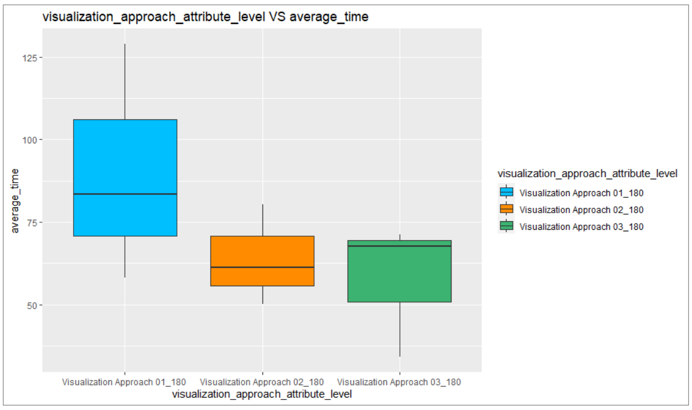
(b) 90 vertical attribute level



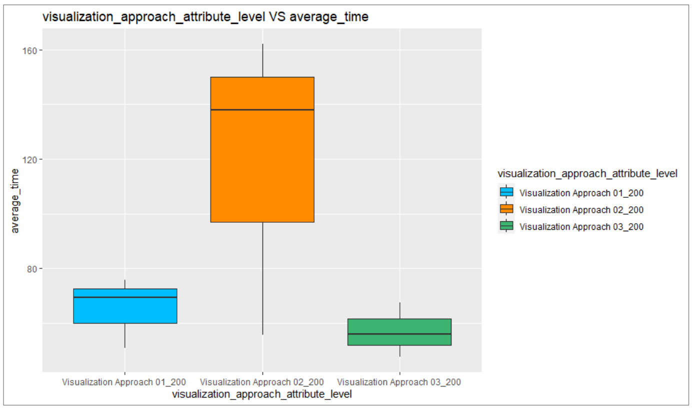
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 13: Boxplots indicating the overall efficiency of each visualization approaches at different vertical attribute levels.

5.1.2 Efficiency for counting vertical attributes

In each task, there was a special question (q4) for counting the vertical attributes in the given attribute category. Efficiency for counting the vertical attributes was computed by considering the time taken for this question (q4). Table 7 presents the efficiency results for q4.

Table 7: Bootstrapping results: Influence of the visualization approach on the time needed to complete q4 at different vertical attribute levels.

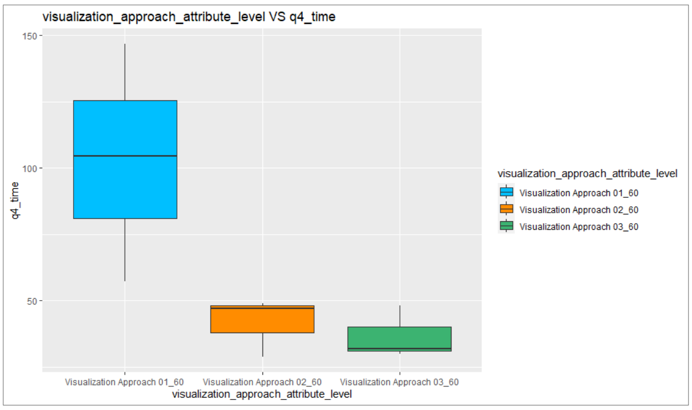
Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference (Seconds)	CI Low	CI High	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	-61.117	-104.263	-21.597	-0.311	21.683
		90	1.493	-43.597	32.463	0.133	18.559
		120	90.450	10.087	135.850	0.506	32.837
		150	-13.160	-113.333	68.927	-0.651	47.576
		180	-2.197	-62.740	40.530	0.329	26.072
		200	65.287	-17.407	174.713	0.443	47.583
		Overall	13.459	-17.043	48.075	0.191	16.781
Scrolling Baseline Approach	Zoomable circle packing Approach	60	-66.107	-109.897	-24.837	0.106	21.460
		90	23.620	-9.307	49.807	-0.036	15.958
		120	59.510	20.003	125.463	-0.065	27.158
		150	-30.657	-132.437	31.767	-0.289	41.331
		180	-4.833	-60.667	45.567	0.680	28.980
		200	-0.397	.24,707	14.463	-0.002	9.563
		Overall	-3.144	-30.245	19.832	0.156	12.800
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	-4.990	-17.127	8.440	0.122	7.000
		90	22.127	-6.237	55.297	0.172	16.126
		120	-30.940	-104.160	69.977	0.077	42.771
		150	-17.497	-86.267	23.917	-0.365	26.732
		180	-2.637	-48.793	56.627	-0.265	26.905
		200	-65.683	-183.753	8.203	0.712	47.834
		Overall	-16.603	-50.055	11.101	-0.162	15.432

The key takeaways are:

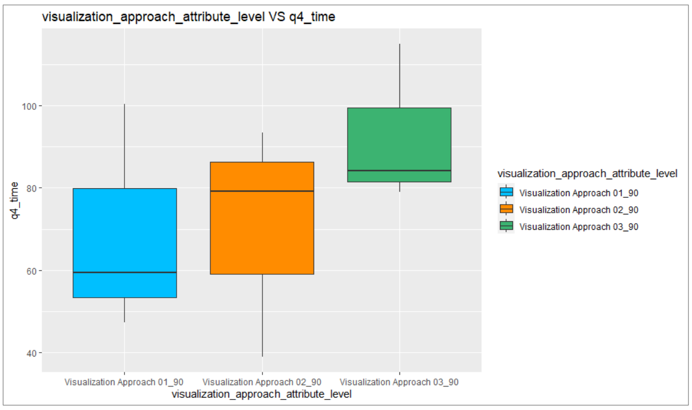
- Scrolling baseline approach vs Spiral-type leaflet markers approach: The spiral-type leaflet markers approach was significantly faster at the 60 vertical attribute level and significantly slower at the 120 vertical attribute level. For other vertical attribute levels, each visualization approach had a slight advantage, but the advantages were not statistically significant.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach was significantly faster at the 60 vertical attribute level, while the scrolling baseline approach was significantly faster at the 120 vertical attribute level. For other vertical attribute levels, each visualization approach had a slight advantage, but the advantages were not statistically significant.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: Each visualization approach had a slight advantage for some vertical attribute levels, but the advantages were not statistically significant.

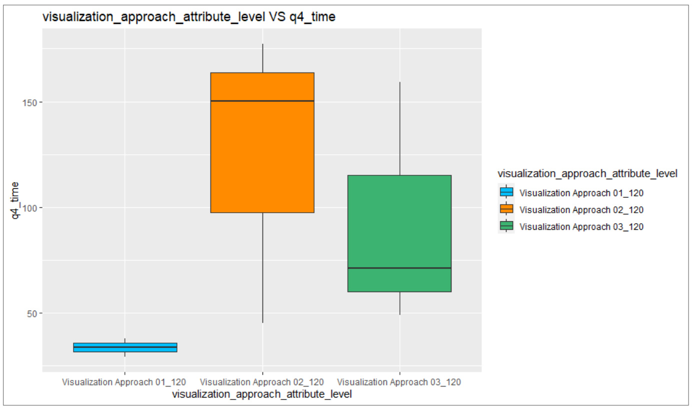
Figure 14 illustrates the graphical representation of efficiency of q4 for three visualization approaches at different vertical attribute levels.



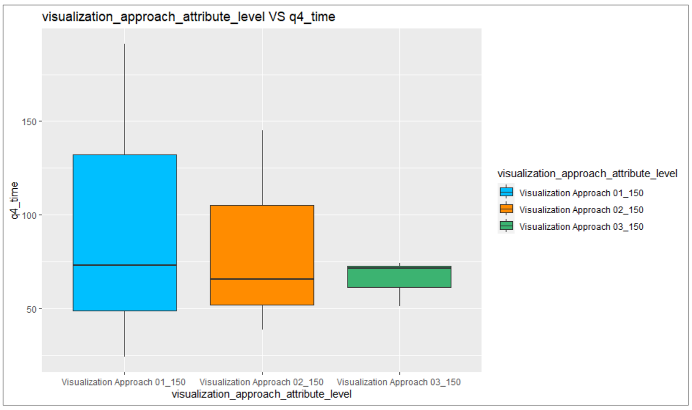
(a) 60 vertical attribute level



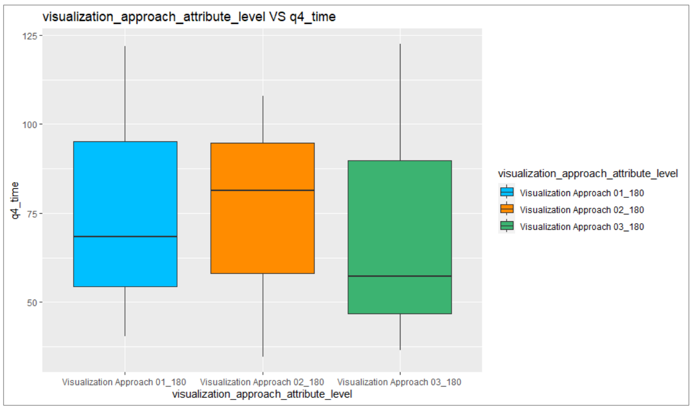
(b) 90 vertical attribute level



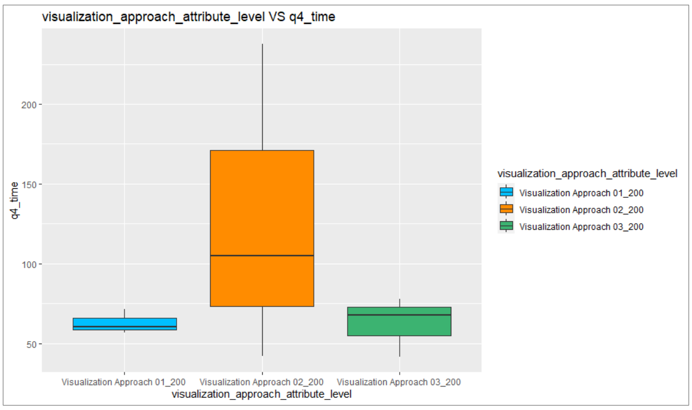
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 14: Boxplots indicating the efficiency of q4 for three visualization approaches at different vertical attribute levels.

5.1.3 Efficiency for identifying the attribute categories of vertical context

In each task, question (q5) was specially included for identifying the attributes categories of vertical context. Efficiency for counting the vertical attributes was computed by considering the time taken for this question (q5). Table 8 presents the efficiency results for q5.

Table 8: Bootstrapping results: Influence of the visualization approach on the time needed to complete q5 at different vertical attribute levels.

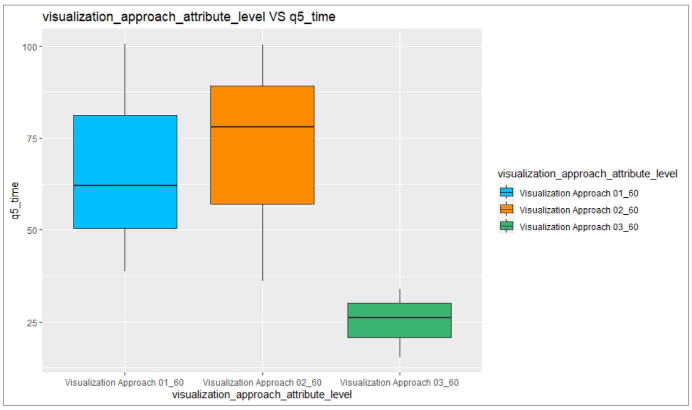
Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference (Seconds)	CI_{Low}	CI_{High}	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	4.390	-43.810	38.940	-0.216	21.069
		90	-19.683	-71.607	13.353	0.386	20.940
		120	0.810	-18.143	15.647	-0.164	8.802
		150	-19.260	-71.100	22.403	0.307	23.693
		180	-30.757	-68.097	-10.867	0.115	14.191
		200	30.750	-22.077	62.990	0.432	21.098
		Overall	-5.625	-23.941	12.248	0.099	9.312
Scrolling Baseline Approach	Zoomable circle packing Approach	60	-41.932	-77.850	-17.743	0.038	15.109
		90	-32.127	-81.123	6.213	-0.562	22.410
		120	40.610	24.437	76.537	0.009	11.106
		150	4.283	-49.803	37.653	0.010	22.875
		180	-10.447	-50.437	14.367	-0.394	16.541
		200	3.440	-35.667	39.017	0.367	18.890
		Overall	-6.032	-24.251	11.157	0.018	8.902
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	-46.313	-74.120	-10.923	0.273	15.891
		90	-12.443	-31.720	12.263	0.050	11.582
		120	39.800	15.010	72.403	0.246	14.022
		150	23.543	-18.663	59.430	0.057	20.003
		180	20.280	1.797	36.190	0.044	9.174
		200	-27.310	-72.247	22.020	-0.287	25.107
		Overall	-0.407	-18.547	16.377	-0.080	9.026

The key takeaways are:

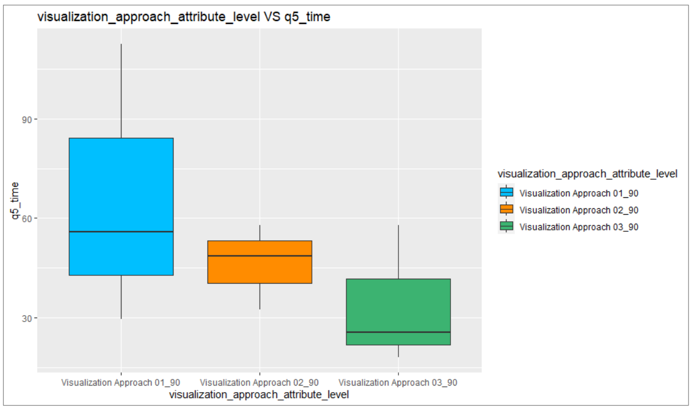
- Scrolling baseline approach vs Spiral-type leaflet markers approach: The spiral-type Leaflet markers method demonstrated significantly higher speed specifically at the 180 vertical attribute. While for other vertical attribute levels, each visualization approach exhibited a slight advantage, these advantages did not reach statistical significance.
- Scrolling baseline approach vs Zoomable circle packing approach: The speed of the zoomable circle packing method showed a significant increase at the 60 vertical attribute level, whereas it exhibited a notable decrease at the 120 vertical attribute level. For other vertical attribute levels, each visualization approach held a slight advantage, but these advantages did not reach statistical significance.
- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The Spiral-type leaflet markers approach demonstrated significantly faster performance at the 120

and 180 vertical attribute levels, while the Zoomable circle packing approach exhibited significantly higher efficiency at the 60 vertical attribute level. Although each visualization approach held a slight advantage for certain vertical attribute levels, these advantages did not reach statistical significance.

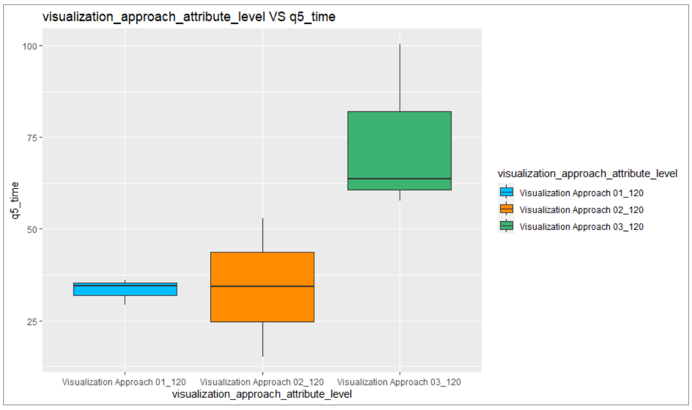
Figure 15 illustrates the graphical representation of the efficiency of q5 for three visualization approaches at various vertical attribute levels.



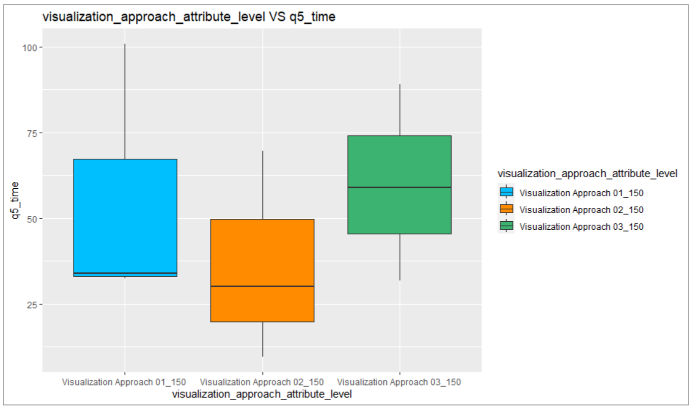
(a) 60 vertical attribute level



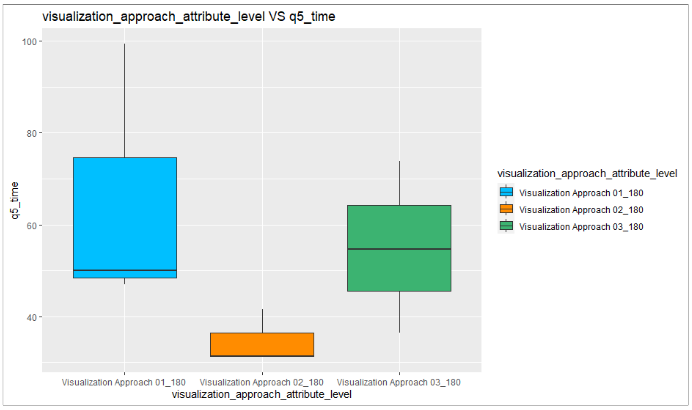
(b) 90 vertical attribute level



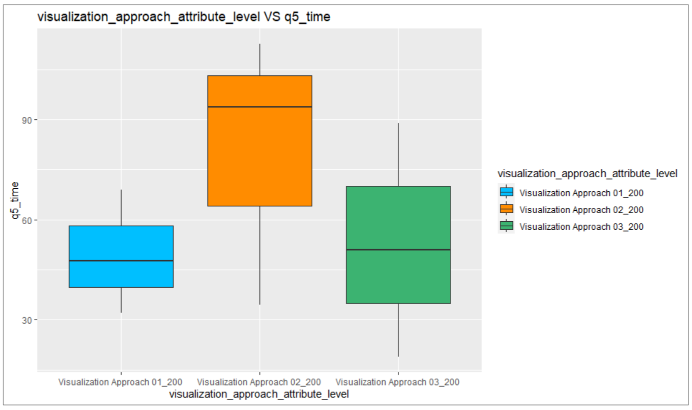
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 15: Boxplots indicating the efficiency of q5 for three visualization approaches at different vertical attribute levels.

5.2 Effectiveness

5.2.1 Overall effectiveness

Table 9 displays the overall effectiveness outcomes, where a higher score indicates a greater number of correctly answered questions. Each task consisted of five questions, and participants received effectiveness scores of 100, 80, 60, 40, or 20 based on the number of questions answered correctly (five, four, three, two, or one respectively). Those who did not answer all five questions correctly received a score of zero.

Table 9: Bootstrapping results: Influence of the visualization approach on the overall effectiveness at different vertical attribute levels.

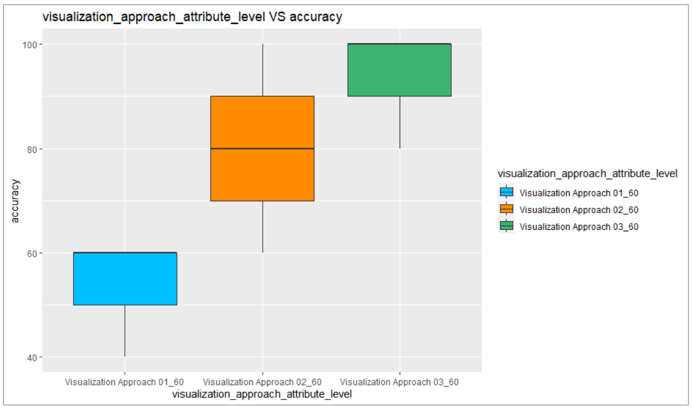
Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference	CI $_{Low}$	CI $_{High}$	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	26.667	0.000	40.000	-0.085	10.969
		90	20.000	0.000	33.333	-0.101	9.410
		120	-33.333	-60.000	-26.667	0.005	7.769
		150	-40.000	-60.000	-26.667	0.219	9.574
		180	-6.667	-40.000	6.667	-0.029	12.332
		200	-13.333	-33.333	6.667	-0.080	12.063
		Overall	-7.778	-20.000	3.333	-0.044	6.092
Scrolling Baseline Approach	Zoomable circle packing Approach	60	40.000	20.000	46.667	0.119	7.765
		90	13.333	0.000	20.000	-0.037	5.524
		120	-6.667	-33.333	6.667	0.073	10.753
		150	-6.667	-20.000	-6.667	-0.080	5.406
		180	20.000	0.000	26.667	-0.040	7.758
		200	-20.000	-40.000	0.000	0.185	12.294
		Overall	6.667	-5.556	16.667	0.005	5.739
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	13.333	-13.333	26.667	-0.001	10.988
		90	-6.667	-33.333	6.667	-0.203	10.914
		120	26.667	0.000	40.000	0.011	11.002
		150	33.333	6.667	46.667	-0.028	10.954
		180	26.667	6.667	46.667	0.263	12.420
		200	-6.667	-20.000	13.333	0.077	7.789
		Overall	16.667	-22.222	38.889	-0.121	15.423

The key takeaways are:

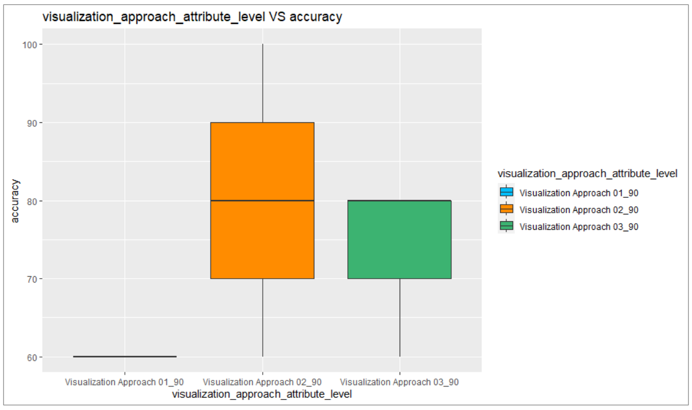
- Scrolling baseline approach vs Spiral-type leaflet markers approach: The spiral-type leaflet markers approach significantly improved result accuracy at the 60 and 90 vertical attribute levels, distinguishing itself from other methods. Likewise, the scrolling baseline approach demonstrated enhanced accuracy at the 120 and 150 vertical attribute levels, exhibiting a significant difference from other approaches.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach demonstrated a significant advantage at the 60, 90, and 180 vertical attribute levels. In contrast, the Scrolling baseline approach showed a significant advantage only at the 150 vertical attribute level.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The zoomable circle packing approach showed a significant advantage at the 120, 150, and 180 vertical attribute levels, as well as overall.

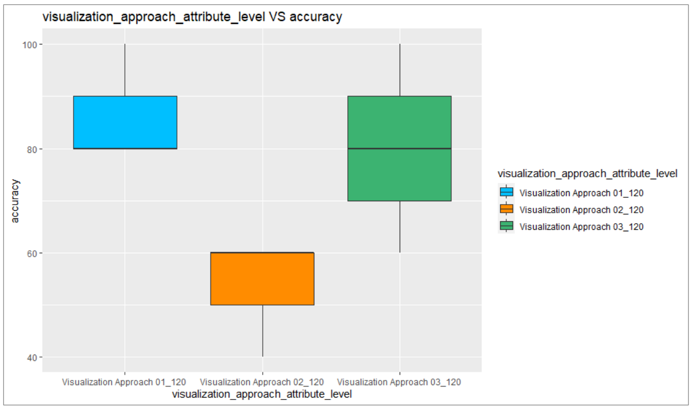
Figure 16 illustrates the graphical representation of overall effectiveness of each visualization approaches at different vertical attribute levels.



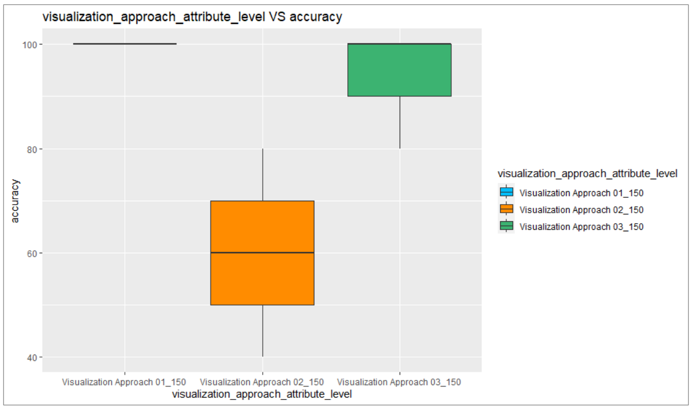
(a) 60 vertical attribute level



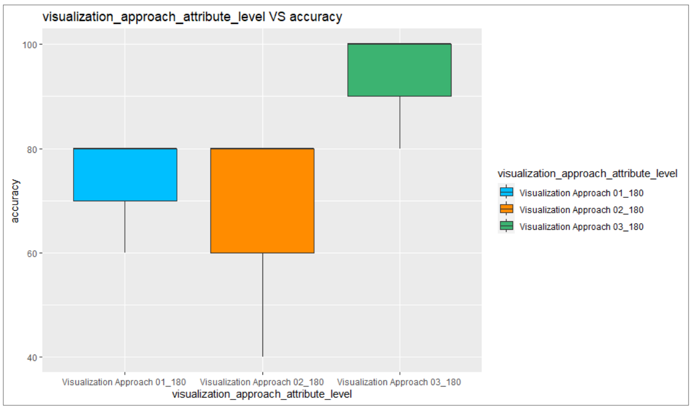
(b) 90 vertical attribute level



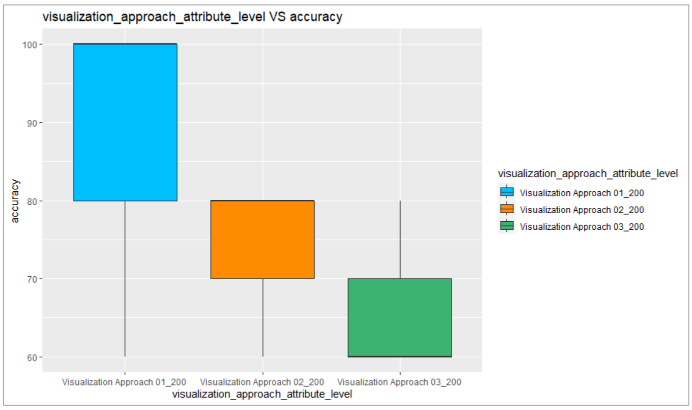
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 16: Boxplots indicating the overall effectiveness of each visualization approaches at different vertical attribute levels.

5.2.2 Effectiveness for counting vertical attributes

Each task included a specific question (q4) designed for counting vertical attributes within the given attribute category. Table 10 represents the accuracy score for q4, with participants receiving an effectiveness score of 100 if they answered correctly. Those who did not provide the correct answer received a score of zero.

Table 10: Bootstrapping results: Influence of the visualization approach on the effectiveness of q4 at different vertical attribute levels.

Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference	CI_{Low}	CI_{High}	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	33.333	-66.667	66.667	-0.287	38.442
		90	66.667	0.000	66.667	0.773	26.824
		120	-66.667	-100.000	-33.333	-0.120	27.385
		150			*****		
		180	33.333	-66.667	66.667	0.313	38.221
		200			*****		
		Overall	-22.222	-55.556	11.111	-0.431	16.112
Scrolling Baseline Approach	Zoomable circle packing Approach	60	33.333	-66.667	66.667	-1.013	38.709
		90			*****		
		120	0.000	-100.000	33.333	-0.220	38.228
		150					*****
		180	66.667	0.000	100.000	-0.493	27.486
		200			*****		
		Overall	16.667	-16.667	44.444	0.143	15.683
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	0.000	-100.000	33.333	0.860	38.537
		90	33.333	0.000	66.667	-0.387	27.031
		120	66.667	0.000	100.000	0.240	27.529
		150			*****		
		180	33.333	0.000	66.667	0.640	27.059
		200			*****		
		Overall	38.889	5.556	66.667	0.030	15.249

***** Since all the values within the each group were identical, it was not possible to calculate the confidence intervals.

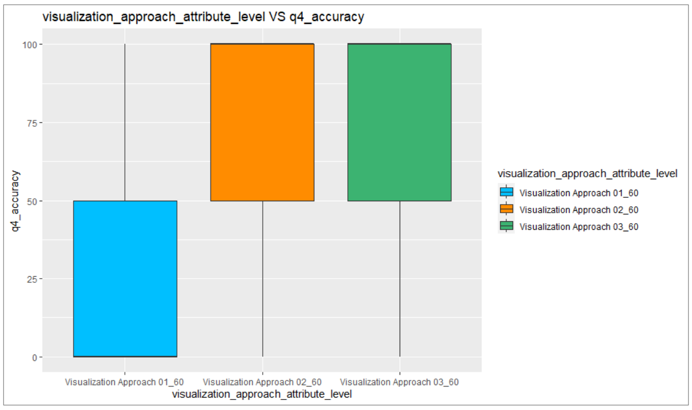
The key takeaways are:

- Scrolling baseline approach vs Spiral-type leaflet markers approach: The scrolling baseline approach significantly enhanced result accuracy at the 120, 150, and 200 vertical attribute levels, setting it apart from other method. Similarly, the spiral-type leaflet markers approach showed improved accuracy at the 90 vertical attribute level, demonstrating a significant difference from other approach.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach demonstrated a significant advantage at the 90, and 180 vertical

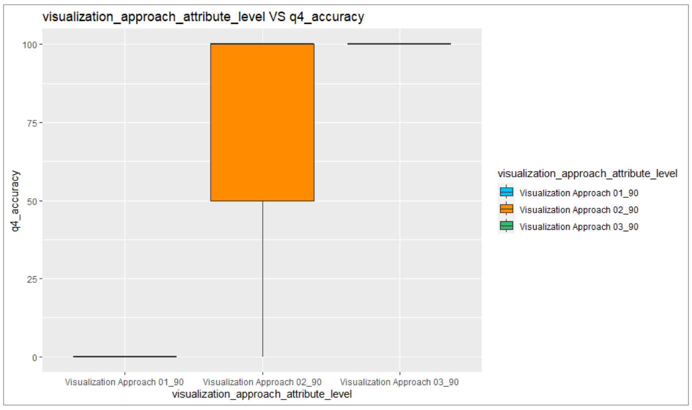
attribute levels. In contrast, the Scrolling baseline approach showed a significant advantage only at the 200 vertical attribute level.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The zoomable circle packing approach showed a significant advantage at the 90, 120, 150, and 180 vertical attribute levels, as well as overall.

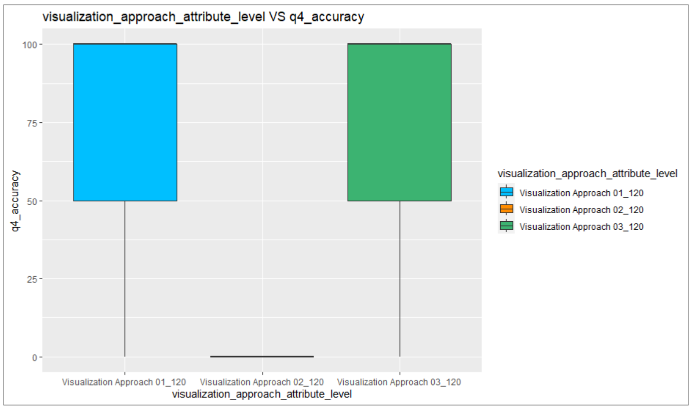
Figure 17 illustrates the graphical representation of effectiveness of q4 for three visualization approaches at different vertical attribute levels.



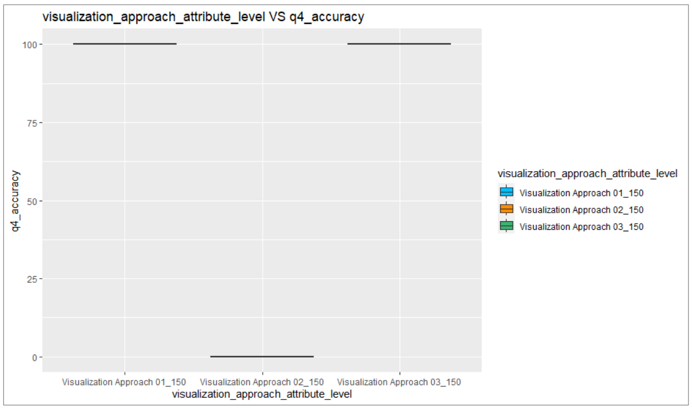
(a) 60 vertical attribute level



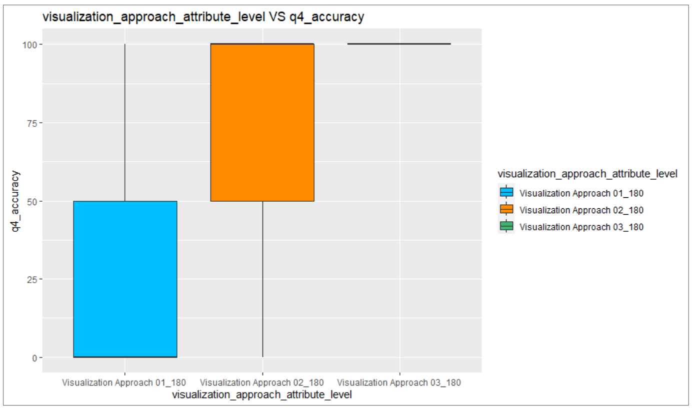
(b) 90 vertical attribute level



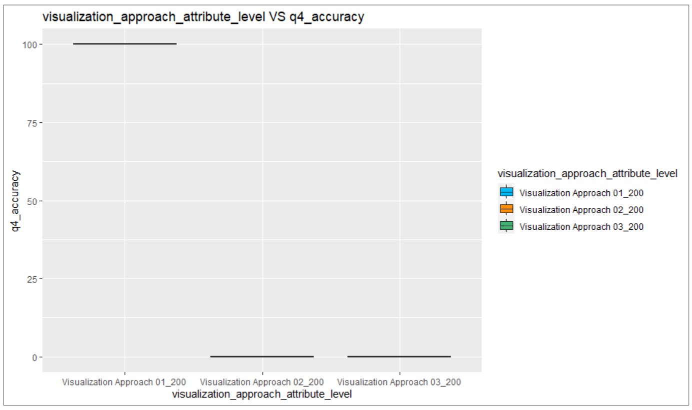
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 17: Boxplots indicating the effectiveness of q4 for three visualization approaches at different vertical attribute levels.

5.2.3 Effectiveness for identifying the attribute categories of vertical context

Each task included a specific question (q5) designed for identifying the attributes categories of vertical context. Table 11 represents the accuracy score for q5, with participants receiving an effectiveness score of 100 if they answered correctly. Those who did not provide the correct answer received a score of zero.

Table 11: Bootstrapping results: Influence of the visualization approach on the effectiveness of q5 at different vertical attribute levels.

Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference	CI Low	CI High	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	33.333	-66.667	66.667	-0.293	38.629
		90	66.667	0.000	100.000	-0.133	27.514
		120	-33.333	-100.000	0.000	0.007	27.389
		150	-66.667	-100.000	-33.333	-0.287	27.151
		180	-33.333	-100.000	0.000	0.607	27.154
		200	33.333	0.000	66.667	0.593	27.374
		Overall	0.000	-38.889	27.778	0.246	16.160
Scrolling Baseline Approach	Zoomable circle packing Approach	60	66.667	0.000	100.000	0.087	27.259
		90	33.333	-66.667	66.667	0.567	38.381
		120	-33.333	-100.000	0.000	0.707	27.074
		150	*****				
		180	66.667	0.000	100.000	-0.253	26.867
		200	-33.333	-100.000	33.333	-0.587	38.609
		Overall	16.667	-16.667	38.889	-0.316	15.156
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	33.333	0.000	66.667	0.513	27.246
		90	-33.333	-100.000	0.000	0.387	27.260
		120	0.000	-100.000	33.333	0.113	38.106
		150	66.667	0.000	100.000	-0.247	27.412
		180	*****				
		200	-66.667	-100.000	-33.333	0.067	27.033
		Overall	16.667	-22.222	38.889	-0.121	15.423

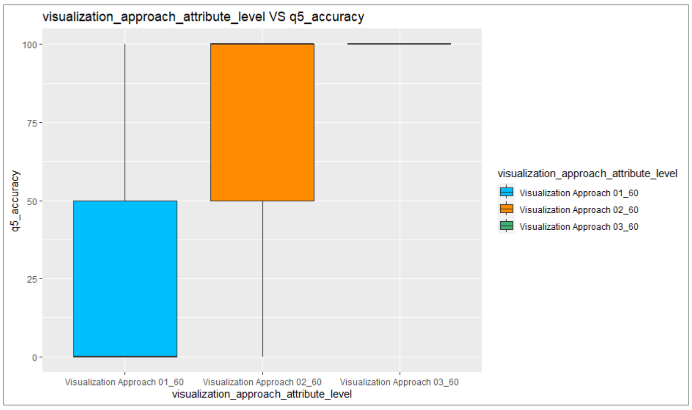
***** Since all the values within the each group were identical, it was not possible to calculate the confidence intervals.

The key takeaways are:

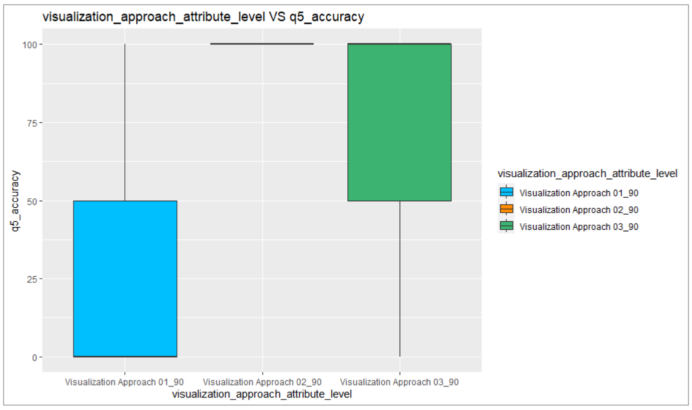
- Scrolling baseline approach vs Spiral-type leaflet markers approach: The scrolling baseline approach significantly enhanced result accuracy at the 150 vertical attribute level, setting it apart from other method. Similarly, the spiral-type leaflet markers approach showed improved accuracy at the 90, 200 vertical attribute level, demonstrating a significant difference from other approach.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing method exhibited a significant advantage at the 60 and 180 vertical attribute levels. While both approaches displayed a slight advantage at certain vertical attribute levels, it is important to note that this advantage was not statistically significant.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The zoomable circle packing method demonstrated significant advantage particularly in relation to the vertical attributes at levels 60, 150, and 180. On the other hand, the spiral-type leaflet markers approach displayed a significant advantage solely at the 200 vertical attribute level.

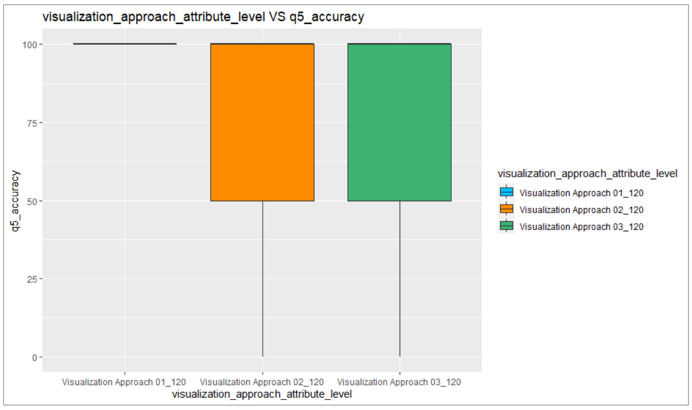
Figure 18 illustrates the graphical representation of effectiveness of q5 for three visualization approaches at different vertical attribute levels.



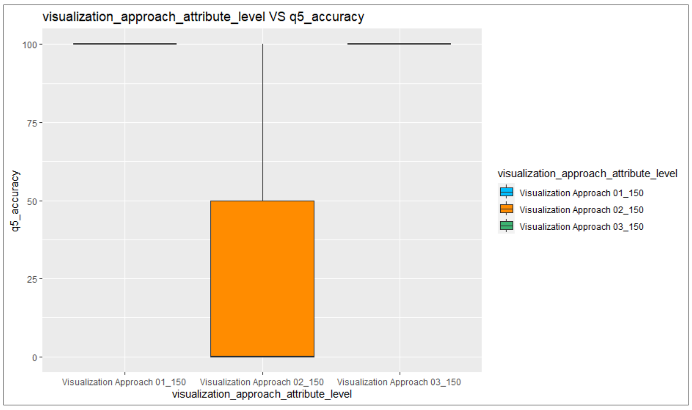
(a) 60 vertical attribute level



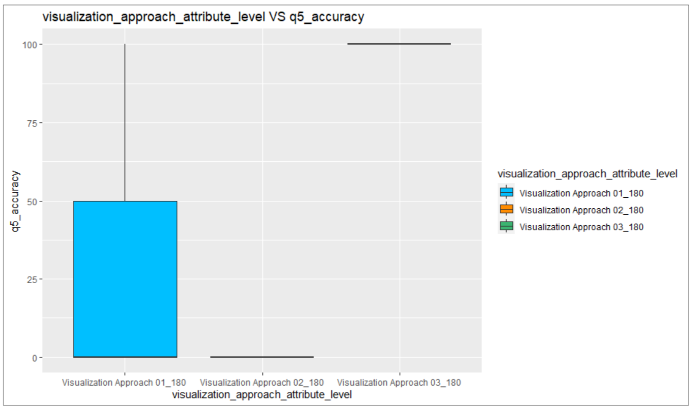
(b) 90 vertical attribute level



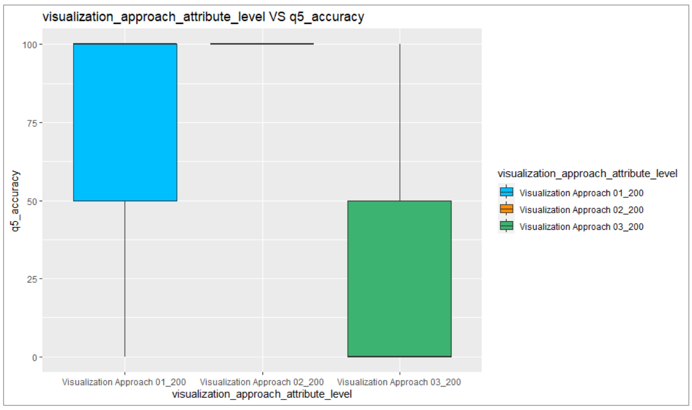
(c) 120 vertical attribute level



(d)150 vertical attribute level



(e) 180 vertical attribute level



(f)200 vertical attribute level

Figure 18: Boxplots indicating the effectiveness of q5 for three visualization approaches at different vertical attribute levels.

5.3 Enjoyment

Enjoyment serves as a subjective gauge, reflecting the pleasure and engagement users experience when interacting with a visualization approach. To quantify this, participants were asked to provide enjoyment scores using a 7-point Likert scale for each visualization approach, ranging from 1 to 7. The conversion process involved transforming these Likert scale ratings into a standardized range of 0 to 100. Specifically, a "Strongly Agree" response corresponded to a score of 100, while a "Strongly Disagree" response equated to a score of 0. Intermediate values were calculated proportionally, aligning with the Likert scale ratings. The tabulated results of these enjoyment scores are presented in Table 12.

Table 12: Bootstrapping results: Influence of the visualization approach on the enjoyment score at different vertical attribute levels.

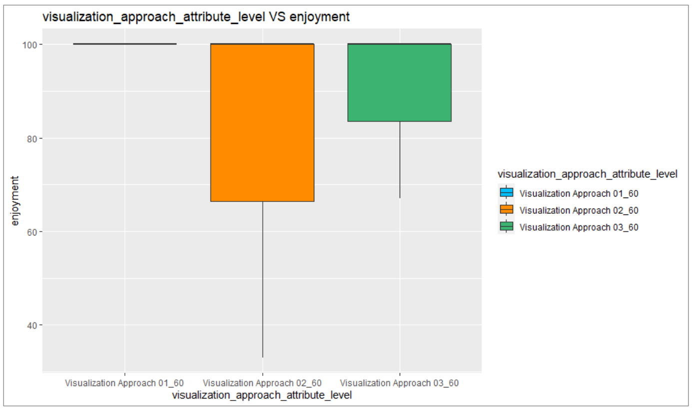
Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference	CI_{Low}	CI_{High}	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	-22.333	-67.000	0.000	-0.009	18.326
		90	-11.000	-44.667	16.667	0.385	16.375
		120	16.667	-44.000	60.667	-0.408	25.744
		150	11.333	-22.000	44.667	0.069	17.061
		180	-44.333	-83.333	-5.667	0.149	19.503
		200	27.333	-44.667	71.667	-0.647	27.813
		Overall	-3.722	-26.833	17.444	0.380	11.090
Scrolling Baseline Approach	Zoomable circle packing Approach	60	-11.000	-33.000	0.000	0.086	9.041
		90	22.333	17.000	27.667	0.061	4.373
		120	44.333	11.333	72.000	-0.258	16.191
		150	27.667	5.333	55.667	-0.153	12.814
		180	11.333	-22.000	33.333	0.461	14.814
		200	49.667	-0.333	83.000	0.247	20.374
		Overall	24.056	9.111	39.883	-0.006	8.051
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	11.333	-22.000	44.667	-0.424	20.191
		90	33.333	0.000	55.667	0.406	15.551
		120	27.667	-5.667	71.667	0.182	21.483
		150	16.333	-11.333	38.667	-0.069	12.695
		180	55.667	11.000	78.000	0.249	17.964
		200	22.333	-22.000	72.333	-0.006	25.584
		Overall	27.778	11.269	46.278	-0.253	8.916

The key takeaways are:

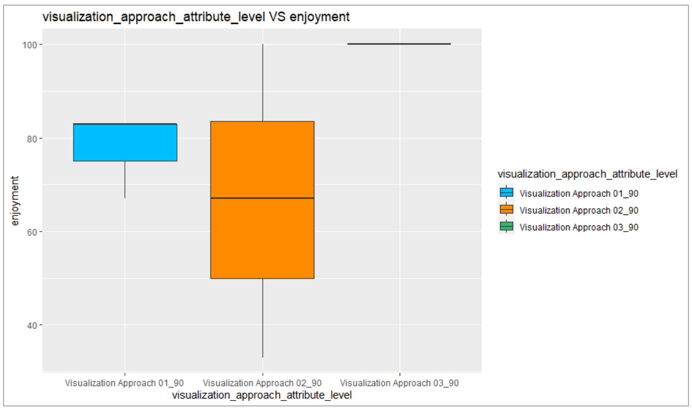
- Scrolling baseline approach vs Spiral-type leaflet markers approach: At the 180 vertical attribute level, the scrolling baseline approach had a statistically significant advantage over the spiral-type leaflet markers approach.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach exhibited significant higher enjoyment scores at the 90, 120, and 150 vertical attribute levels, as well as overall.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The zoomable circle packing approach demonstrated a significant advantage solely at the 90 and 180 vertical attribute levels, as well as overall.

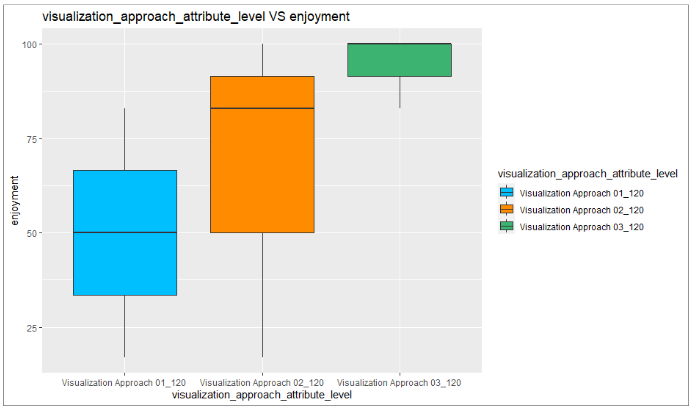
Figure 19 illustrates the graphical representation of enjoyment score for each visualization approaches at different vertical attribute levels.



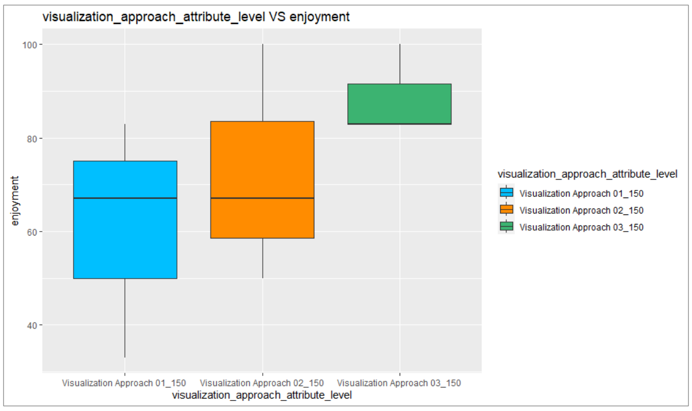
(a) 60 vertical attribute level



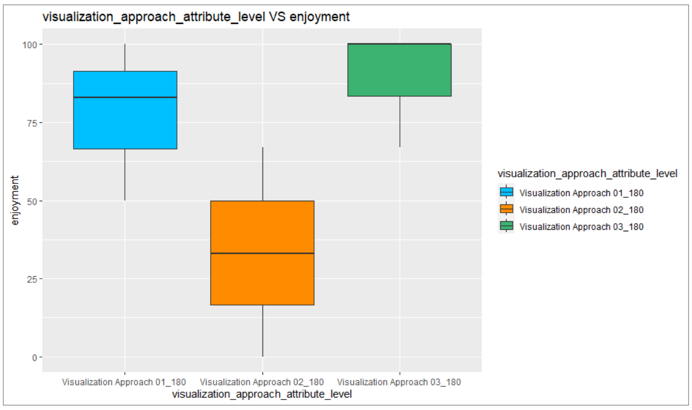
(b) 90 vertical attribute level



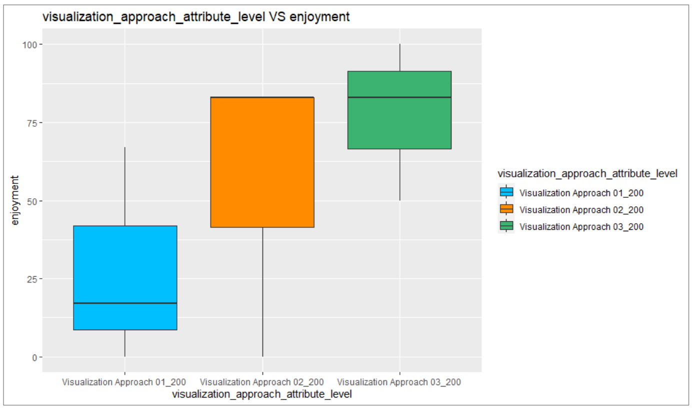
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 19: Boxplots indicating the enjoyment score of each visualization approaches at different vertical attribute levels.

5.4 Usefulness

Usefulness refers to the degree to which a product, service, or system fulfills a practical purpose or provides value to users in achieving their goals. The usefulness scores were obtained through a single feedback question employing a 7-point Likert scale for each visualization approach. Participants rated their experience on a scale ranging from 1 to 7, and the scoring method aligned with that used in the preceding subsection on Enjoyment (Sub section 5.3) . The results of the usefulness scores are presented in Table 13.

Table 13: Bootstrapping results: Influence of the visualization approach on the usefulness score at different vertical attribute levels.

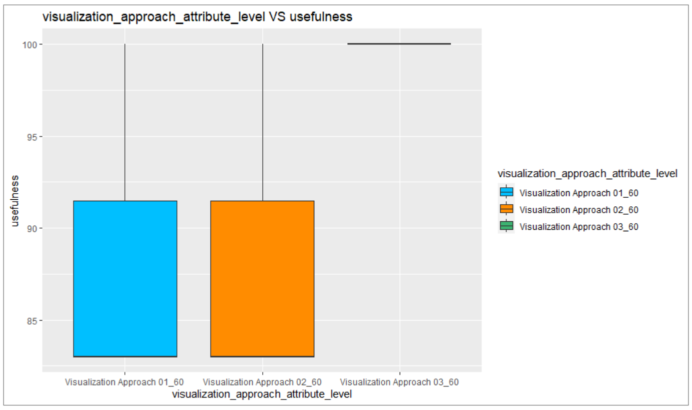
Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference	CI_{Low}	CI_{High}	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	0.000	-17.000	5.667	-0.100	6.571
		90	-33.333	-55.667	-11.000	0.326	12.927
		120	-5.667	-50.000	16.667	-0.004	16.722
		150	-27.667	-50.000	0.333	-0.095	14.396
		180	-38.667	-83.000	-11.000	0.030	18.071
		200	22.000	-22.333	66.000	0.203	22.951
		Overall	-13.889	-32.389	6.389	0.034	9.917
Scrolling Baseline Approach	Zoomable circle packing Approach	60	11.333	0.000	11.333	0.022	4.628
		90	5.667	-17.000	11.333	0.097	6.595
		120	38.667	33.000	44.333	-0.022	4.621
		150	22.333	0.000	50.000	0.556	14.449
		180	33.667	-5.000	55.667	0.052	15.030
		200	55.667	28.000	83.333	-0.004	15.178
		Overall	27.889	14.944	43.556	-0.028	7.238
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	11.333	0.000	17.000	0.016	4.650
		90	39.000	5.667	55.667	0.017	12.893
		120	44.333	17.000	66.333	0.132	16.238
		150	50.000	38.667	61.333	0.212	6.662
		180	72.333	28.000	89.000	-0.140	16.343
		200	33.667	-5.000	72.333	-0.237	21.655
		Overall	41.778	26.162	57.556	0.070	8.090

The key takeaways are:

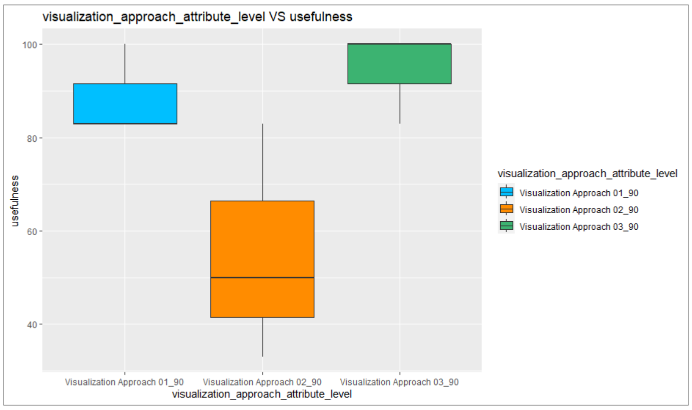
- Scrolling baseline approach vs Spiral-type leaflet markers approach: The scrolling baseline approach exhibited a statistically significant advantage over the spiral-type leaflet markers approach specifically at the 90 and 180 vertical attribute levels.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach showed significantly higher usefulness scores at the 60, 120, 150, and 200 vertical attribute levels, as well as overall. While it maintained a slight advantage at the remaining vertical attribute levels, these advantages did not reach statistical significance.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The zoomable circle packing approach displayed a significant advantage at all attribute levels as well as overall except for the 200 vertical attribute level and advantage was not statistically significant at the 200 vertical attribute level.

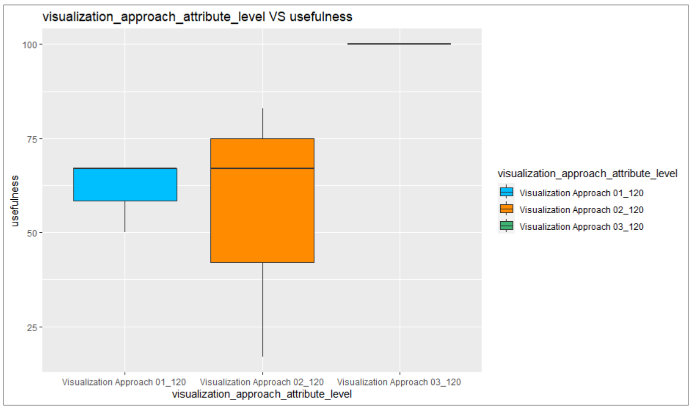
Figure 20 illustrates the graphical representation of usefulness score for each visualization approaches at different vertical attribute levels.



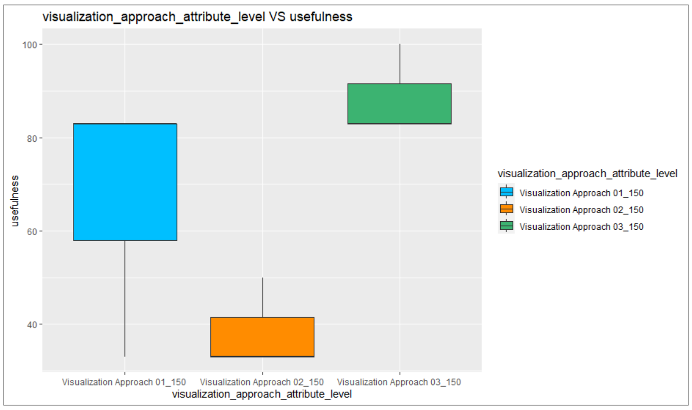
(a) 60 vertical attribute level



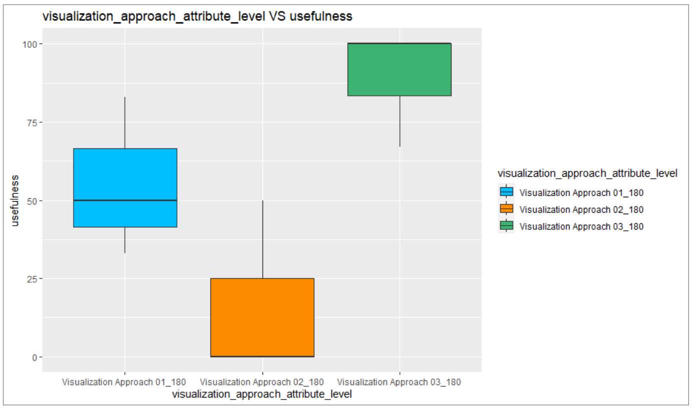
(b) 90 vertical attribute level



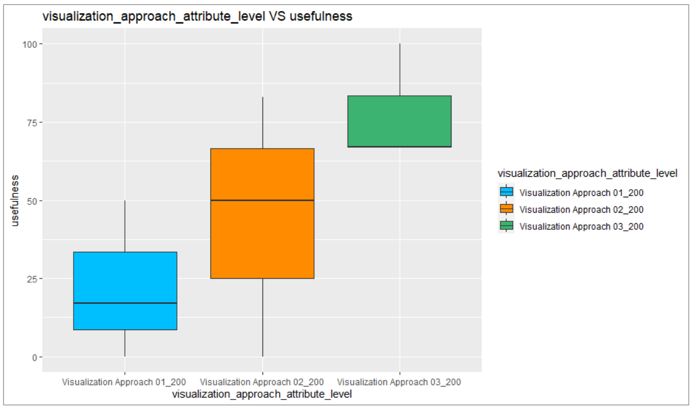
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 20: Boxplots indicating the usefulness score of each visualization approaches at different vertical attribute levels.

5.5 Satisfaction

The satisfaction scores were obtained through a single feedback question employing a 7-point Likert scale for each visualization approach. Participants rated their experience on a scale ranging from 1 to 7, and the scoring method aligned with that used in the preceding subsection on Enjoyment (Sub section 5.3). The results of the satisfaction scores are presented in Table 14.

Table 14: Bootstrapping results: Influence of the visualization approach on the satisfaction score at different vertical attribute levels.

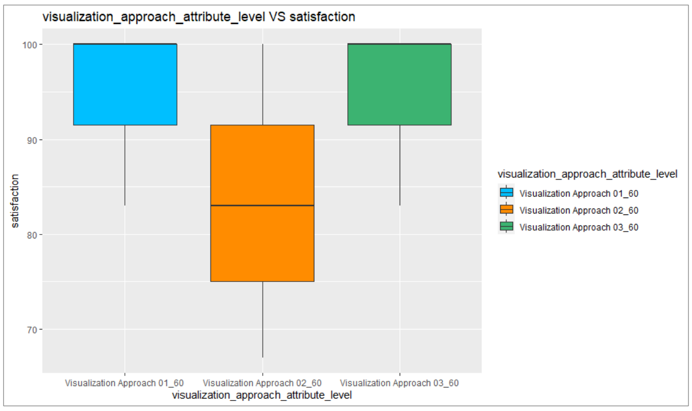
Visualization Approach A (9)	Visualization Approach B	Attribute Level	Mean Difference	CI $_{Low}$	CI $_{High}$	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	-11.000	-27.667	5.667	0.032	9.086
		90	-22.333	-55.667	0.000	0.157	14.126
		120	-22.000	-60.667	17.000	0.183	20.296
		150	-5.000	-16.000	6.000	-0.114	8.918
		180	-61.000	-88.667	-33.333	-0.542	14.293
		200	33.333	-16.333	66.333	0.108	20.788
		Overall	-14.667	-33.056	5.722	0.076	9.819
Scrolling Baseline Approach	Zoomable circle packing Approach	60	0.000	-17.000	5.667	0.045	6.480
		90	5.333	-11.333	22.000	-0.098	9.153
		120	22.333	17.000	27.667	-0.066	4.301
		150	16.667	0.000	33.333	-0.045	10.154
		180	11.000	-11.333	22.333	0.116	8.993
		200	61.000	16.667	88.667	0.369	18.189
		Overall	19.389	6.500	36.889	-0.130	7.497
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	11.000	-11.333	22.333	-0.022	9.042
		90	27.667	5.333	55.667	-0.023	12.708
		120	44.333	0.000	72.000	-0.349	19.619
		150	21.667	16.000	27.333	0.032	4.611
		180	72.000	38.667	88.667	0.129	12.851
		200	27.667	-22.000	60.667	-0.036	19.610
		Overall	34.056	19.333	48.944	-0.107	7.565

The key takeaways are:

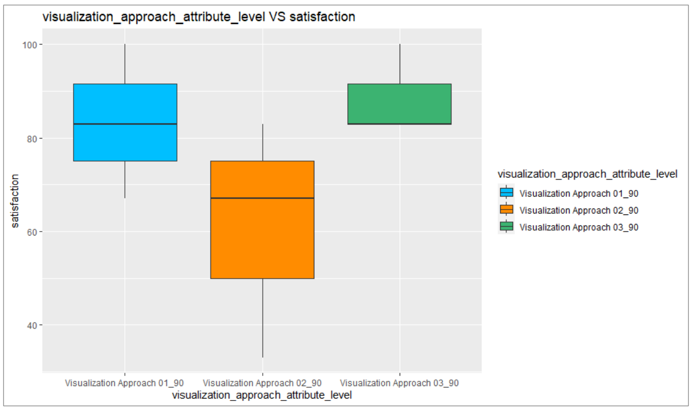
- Scrolling baseline approach vs Spiral-type leaflet markers approach: The scrolling baseline approach exhibited a statistically significant advantage over the spiral-type leaflet markers approach specifically only at the 180 vertical attribute level.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach showed significantly higher satisfaction scores at the 120, 150, and 200 vertical attribute levels, as well as overall. While it maintained a slight advantage at the remaining vertical attribute levels, these advantages did not reach statistical significance.
- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The zoomable circle packing approach displayed a significant advantage at all attribute

levels, as well as overall except for the 60 and 200 vertical attribute levels and advantage was not statistically significant at the 60 and 200 vertical attribute levels.

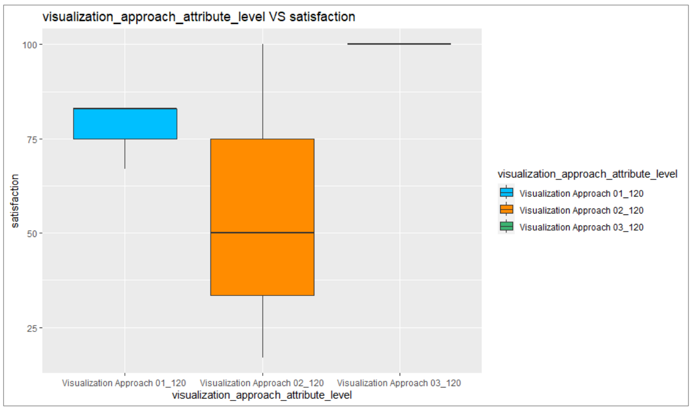
Figure 21 illustrates the graphical representation of satisfaction score for each visualization approaches at different vertical attribute levels.



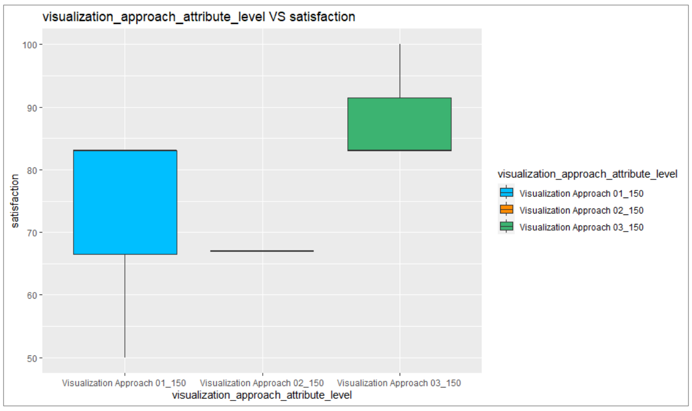
(b) 60 vertical attribute level



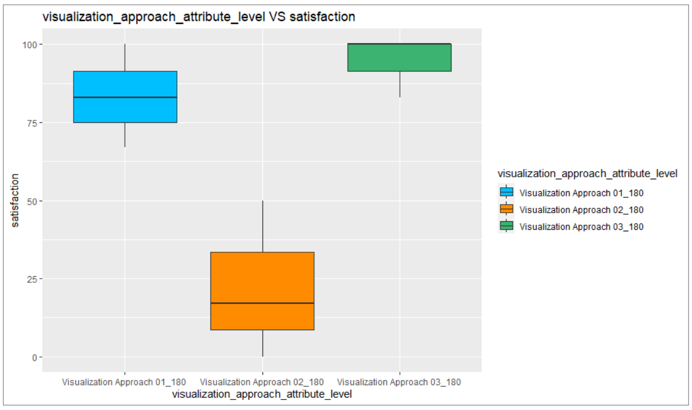
(b) 90 vertical attribute level



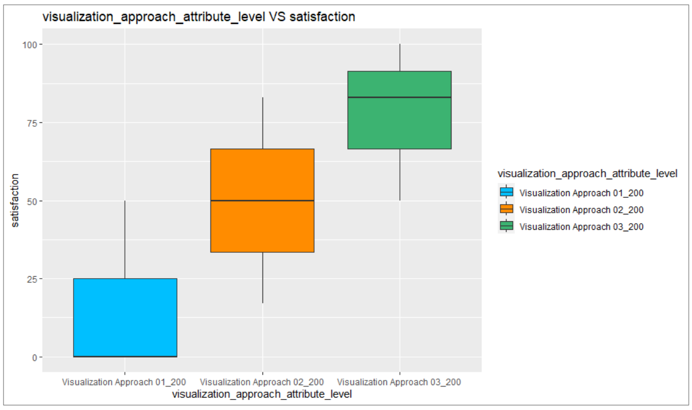
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 31: Boxplots indicating the satisfaction score of each visualization approaches at different vertical attribute levels.

5.6 Ease of use

Ease of use refers to the user-friendliness and simplicity of visualization approach . It reflects how easily individuals can interact with and navigate through a visualization approach without encountering unnecessary complications or difficulties. The scores for ease of use were obtained through a single feedback question employing a 7-point Likert scale for each visualization approach. Participants rated their experience on a scale ranging from 1 to 7, and the scoring method aligned with that used in the preceding subsection on Enjoyment (Sub section 5.3). The results of the scores for ease of use are presented in Table 15.

Table 15: Bootstrapping results: Influence of the visualization approach on the score for ease of use at different vertical attribute levels.

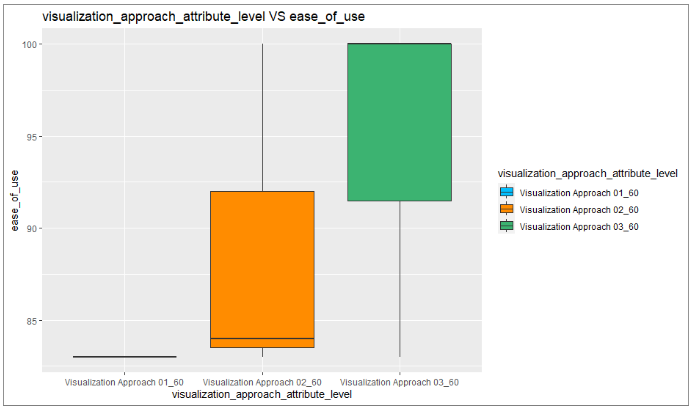
Visualization Approach A	Visualization Approach B	Attribute Level	Mean Difference	CI_{Low}	CI_{High}	Bias	SE
Scrolling Baseline Approach	Spiral-type Leaflet markers Approach	60	6.000	0.000	17.000	-0.017	4.598
		90	-61.333	-67.000	-55.667	0.101	4.548
		120	-22.000	-66.000	0.000	0.162	16.846
		150	-28.000	-55.667	-0.333	0.028	14.180
		180	-44.333	-77.667	5.333	0.396	21.550
		200	5.667	-49.667	61.000	-0.159	28.712
		Overall	-24.000	-40.611	-5.444	-0.028	9.046
Scrolling Baseline Approach	Zoomable circle packing Approach	60	11.333	0.000	11.333	0.118	4.611
		90	-5.333	-33.000	6.000	-0.210	10.261
		120	22.333	17.000	27.667	-0.002	4.409
		150	0.000	-39.000	22.333	-0.093	15.785
		180	0.000	-50.000	22.333	-0.540	19.071
		200	44.333	5.667	83.333	-0.187	20.356
		Overall	12.111	-0.778	26.056	-0.026	6.866
Spiral-type Leaflet markers Approach	Zoomable circle packing Approach	60	5.333	-11.667	16.000	-0.033	6.516
		90	56.000	34.000	56.000	0.099	8.911
		120	44.333	17.000	66.333	-0.436	16.491
		150	28.000	-17.951	50.333	0.075	17.966
		180	44.333	-27.667	88.667	0.104	27.705
		200	38.667	-17.000	71.667	0.113	21.591
		Overall	36.111	17.444	51.788	-0.005	8.760

The key takeaways are:

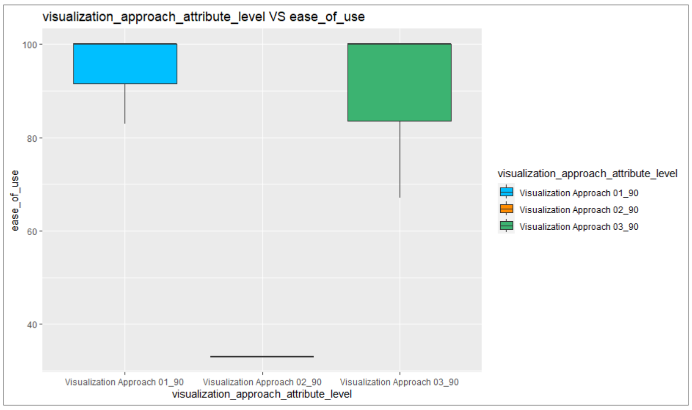
- Scrolling baseline approach vs Spiral-type leaflet markers approach: The scrolling baseline method demonstrated a statistically significant advantage compared to the spiral-type leaflet markers approach, particularly at the 90 and 150 vertical attribute levels, as well as overall. Conversely, the spiral-type Leaflet markers approach exhibited a significant advantage solely at the 60 vertical attribute limit.
- Scrolling baseline approach vs Zoomable circle packing approach: The zoomable circle packing approach showed significantly higher usefulness scores at the 60, 120 and 200 vertical attribute levels.

- Spiral-type leaflet markers approach vs Zoomable circle packing approach: The zoomable circle packing approach exhibited a significant advantage, demonstrating statistical significance, particularly at the 90 and 120 vertical attribute levels, as well as overall.

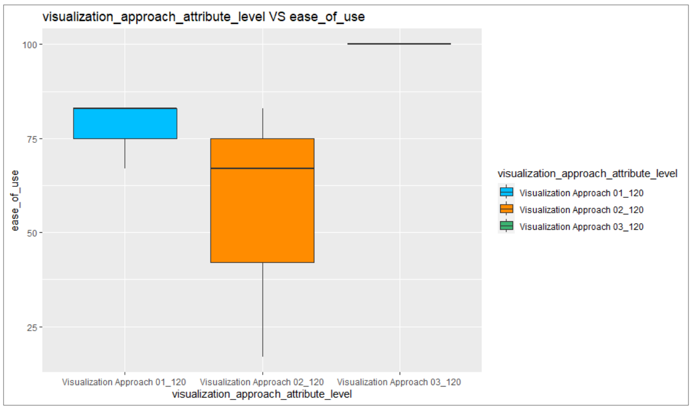
Figure 22 illustrates the graphical representation of ease of use score for each visualization approaches at different vertical attribute levels.



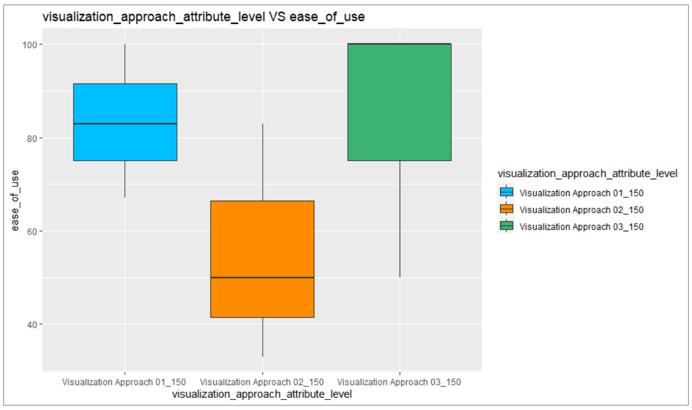
(a) 60 vertical attribute level



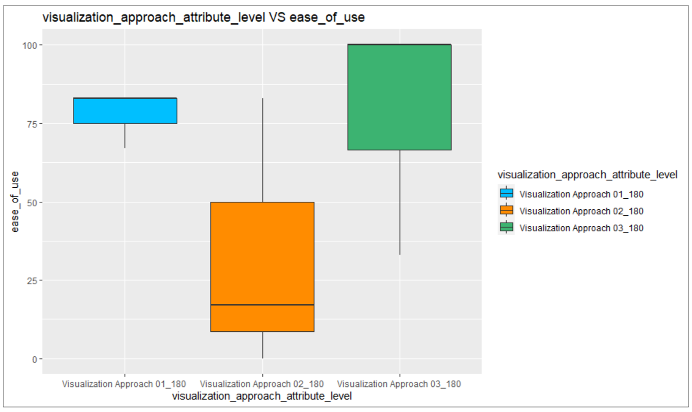
(b) 90 vertical attribute level



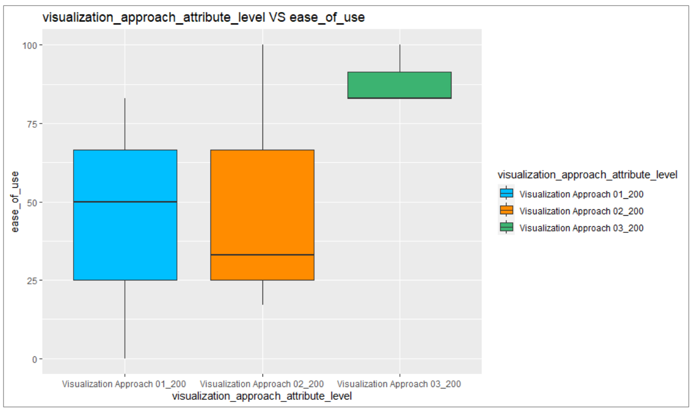
(c) 120 vertical attribute level



(d) 150 vertical attribute level



(e) 180 vertical attribute level



(f) 200 vertical attribute level

Figure 42: Boxplots indicating the ease of use score of each visualization approaches at different vertical attribute levels.

5.7 Participants' subjective preference

During the last stage of the user experiment, participants were asked to respond to the question, "Considering the three visualization approaches you've interacted with, could you please rank them in order of preference based on which one you found most effective in helping you answer the questions?" Participants were then instructed to provide their preferences by assigning Rank 1, Rank 2, and Rank 3 to the respective visualization approaches. Table 16 provides a breakdown of the vote counts for each rank assigned to the three visualization approaches. Additionally, Figure 23 offers a visual representation of these counts, showcasing the comparative preferences for each rank across the three visualization approaches.

Table 16: The counts of votes for each rank

Visualization approach	Rank 1	Rank 2	Rank 3
Scrolling baseline approach	3	13	2
Spiral-type leaflet markers approach	0	2	16
Zoomable circle packing approach	15	3	0

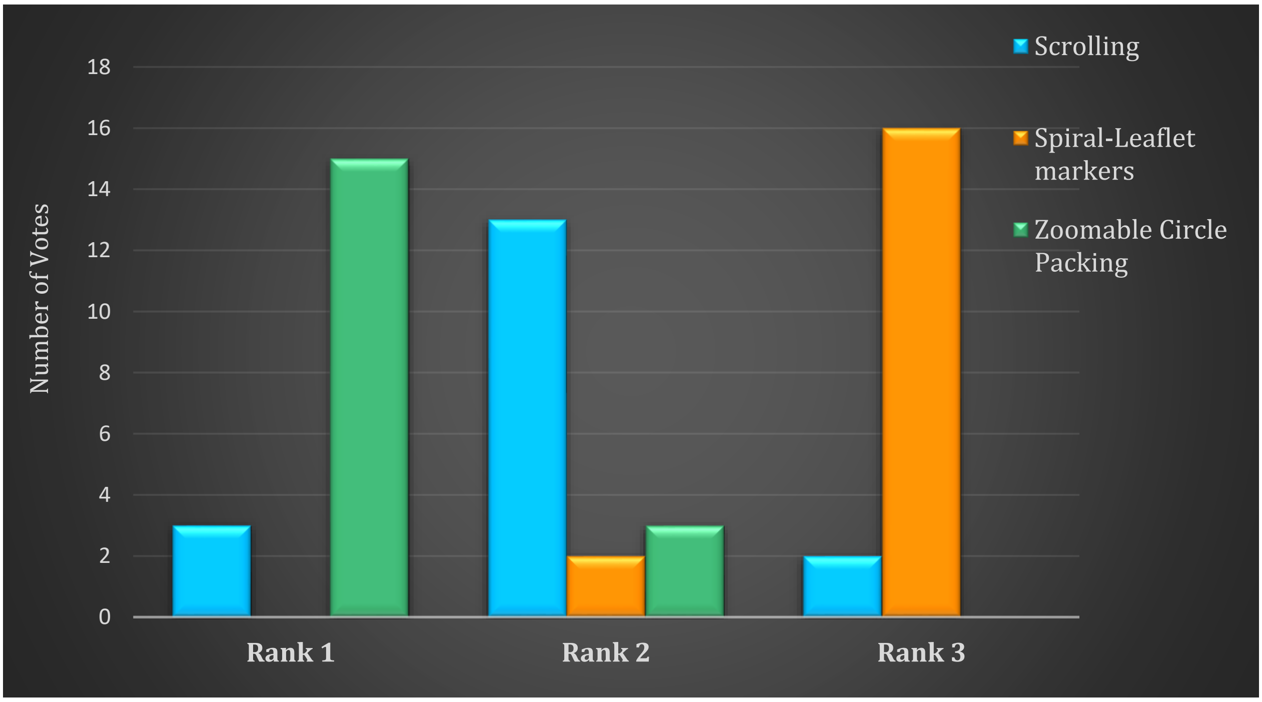


Figure 53: A bar graph illustrates the counts of votes for each rank for three visualization approaches.

The zoomable circle packing visualization approach emerged as the most favored among participants, garnering 15 out of 18 votes as Rank 1. In contrast, the Spiral-type leaflet markers approach received the least preference with 16 out of 18 votes as Rank 3, making it the least favored.

Subsequently, participants were prompted to respond to the question, "Could you please provide reasons for ranking them?" Based on the participants' responses, the key significant advantages of Zoomable circle packing approach and Scrolling baseline approach mentioned can be summarized as follows: *Zoomable circle packing approach* : Users have the capability to zoom in for a detailed inspection of specific attributes and seamlessly zoom out to transition to other attributes. The attributes are thoughtfully organized into clusters, grouping similar ones in close proximity. This systematic arrangement enhances navigation, making it easy for users to locate specific attributes efficiently. *Scrolling baseline approach*: Users can swiftly navigate through attributes by employing a rapid scrolling feature, allowing them to efficiently move through the content and explore different attributes without delays.

Disadvantages of Spiral-type leaflet markers approach and Scrolling baseline approach can be summarized as follows: *Spiral-type leaflet markers approach:* To locate a specific attribute, users need to click on multiple markers, as it can be challenging to distinguish the desired attribute among others within the same category. *Scrolling baseline approach*: The list view arrangement makes it difficult to easily identify attribute counts and discern attribute categories.

5.8 Impacts of participants background

The analysis of participants' backgrounds on dependent variables involved considering several background parameters, namely gender, computer literacy, familiarity with Leaflet.js marker patterns, and familiarity with D3.js zoomable circle packing visualization. The description of how these parameters can be influenced is outlined as follows.

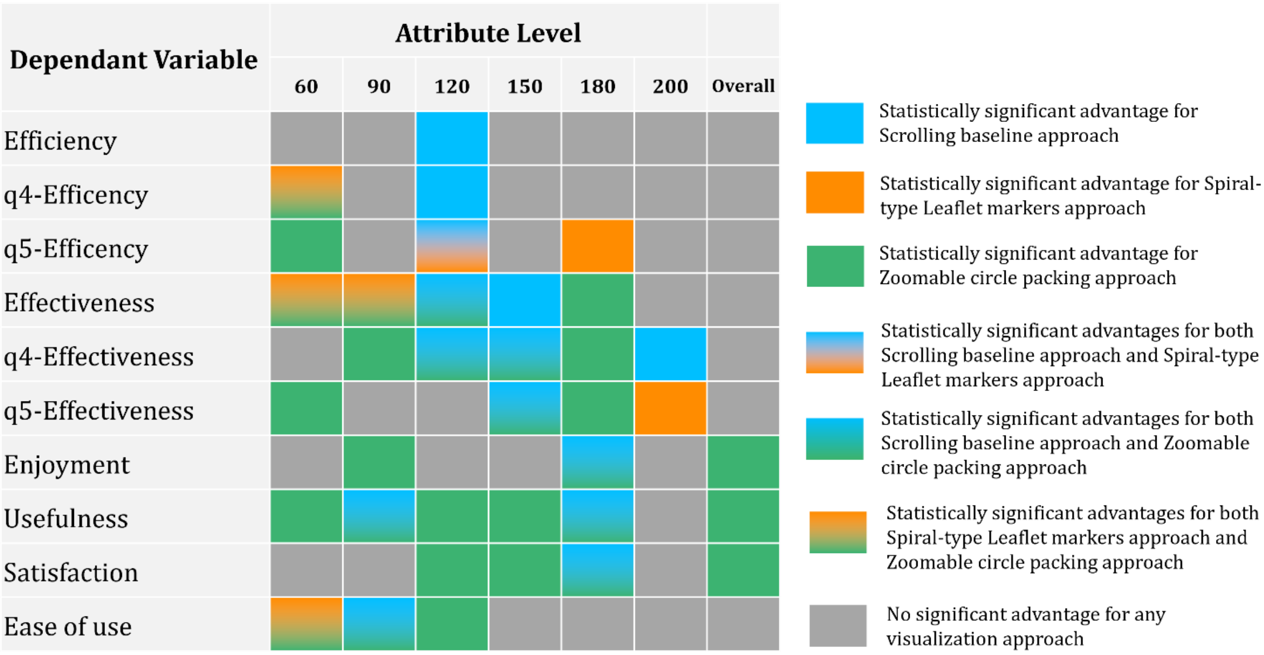
- Gender: Male participants demonstrated a significant faster response only to the zoomable circle packing approach compared to the female participants.
  However, for all the visualization approaches, there were no significant differences observed between males and females for other dependent variables (effectiveness, enjoyment, satisfaction, ease of use).

- computer literacy: Across all visualization approaches, no significant differences were identified in terms of the various dependent variables, concerning computer literacy.
- Familiarity with Leaflet.js marker patterns and D3.js zoomable circle packing visualization: Familiarity with Leaflet.js marker patterns and D3.js zoomable circle packing visualization did not result in any significant advantages for any of the dependent variables across all visualization approaches.

6. DISCUSSION

In the previous results section, the visualization approaches were examined through three pairwise comparisons in each table. The visualization approach with a statistically significant advantage was determined for each vertical attribute level as well as overall, and based on the statistical significant advantage, color coding was applied to Table 17. The summary of the statistically significant visualization approach for each vertical attribute level, as well as overall is presented in Table 17.

Table 17: The summary of the statistically significant visualization approach for each vertical attribute level



The three hypotheses are now revisited.

- H1 - *The zoomable circle packing approach will be the best visualization method for deeper understanding the vertical context of geographic locations with 60, 90, 120, 150, 180, 200 attributes. The spiral-type leaflet markers approach and the scrolling baseline approach will be ranked as 2nd and 3rd respectively:* To check this hypothesis, the dependent variables considered were efficiency, effectiveness, enjoyment, usefulness, satisfaction, and ease of use. The best visualization approach for a specific vertical attribute level was determined by assessing the color distribution (number of colored cells) associated with each visualization approach. For attribute level 60, the zoomable circle packing approach achieved the first rank. The Spiral-Leaflet Markers approach secured the second rank, while the Scrolling approach attained the last place. This hypothesis **is supported** for the 60 vertical attribute level.

For attribute levels 90, 120, 150, and 180, the zoomable circle packing approach performed the best, securing the first rank. The Scrolling approach followed in the second position, while the Spiral-Leaflet Markers approach ranked the lowest. This hypothesis **is not supported** for attribute levels 90, 120, 150, and 180.

For attribute level 200, none of the visualization approaches demonstrated any significant advantage and behaved similarly. Consequently, this hypothesis **is not supported** for attribute level 200 as well.

- H2 - *The zoomable circle packing approach is the best visualization method for determining the number of attributes belonging to each attribute category:* To assess this hypothesis, the considered dependent variables were q4-efficiency and q4-effectiveness. q4 was specifically designed to count the vertical attributes within the given attribute category. The best visualization approach for a specific vertical attribute level was determined by assessing the color distribution (number of colored cells) associated with each visualization approach. The zoomable circle packing approach secured the first rank for attribute levels 90 and 180. Consequently, this hypothesis **is supported** for these attribute levels.

  For attribute levels 120 and 200, the first rank was secured by the scrolling baseline approach. Therefore, this hypothesis **is not supported** for 120 and 200 attribute levels. For attribute levels 60 and 150, the zoomable circle packing approach failed to secure the first rank on its own. This implies that, for attribute level 60, the Spiral-type leaflet markers approach also achieved the 1st rank, and for attribute level 150, the Scrolling baseline approach also secured the 1st rank. Consequently, this hypothesis **is not supported** for 60 and 150 attribute levels.

- H3 - *The spiral-type leaflet markers approach is better than the other two visualization approaches for determining the number of main attribute categories:* To assess this hypothesis, the considered dependent variables were q5-efficiency and q5-effectiveness. q5 was specifically designed to identify the attribute categories of vertical context. The best visualization approach for a specific vertical attribute level was determined by assessing the color distribution (number of colored cells) associated with each visualization approach. For attribute level 200, the spiral-type leaflet markers approach achieved the first rank. This hypothesis **is supported** for the 200 vertical attribute level.

For attribute levels 120 and 180, the spital-type leaflet markers approach failed to secure the first rank on its own. This implies that, for attribute level 120, the scrolling approach also achieved the 1st rank, and for attribute level 180, the zoomable circle packing approach also secured the 1st rank. Consequently, this hypothesis **is not supported** for 120 and 180 attribute levels.
For attribute levels 60, 90 and 150, the spiral-type leaflet markers approach failed to secure the first rank. Therefore, this hypothesis **is not supported** for 60, 90 and 150 attribute levels.

The experiment involved a total of 18 participants, with each attribute level having nine data points and each visualization approach for a specific attribute level comprised three data points. However, the limited number of data points led to instances where the average values of dependent variables for certain attribute levels exhibited deviation of statistical outcomes due to the occasional extreme performance of a single participant. For example, in the case of the 120 attribute level using the scrolling baseline approach, one participant completed the task in an exceptionally low time, causing the average time for the scrolling baseline approach at the 120 attribute level to be recorded as lower than the time for other two approaches. This particular scenario was the contributing factor to the presence of statistically significant values in only one or two attribute levels, as depicted in Table 17.

In assessing the overall scores for dependent variables like **usefulness**, **satisfaction**, and **enjoyability**, the **zoomable circle packing approach** demonstrates significant advantages compared to other two visualization methods. Remarkably, this approach consistently outperforms others across the majority of attribute levels, spanning from 60 to 180 attributes, with the exception of attribute level 200.
In terms of effectiveness and ease of use, no approach demonstrates an overall statistical advantage. However, when looking at major attribute levels from 60 to 180 (excluding level 200), the zoomable circle packing approach consistently exhibits significant advantages over the other two visualization approaches. Therefore, for **effectiveness** and **ease of use**, the **zoomable circle packing approach** holds a notable advantage.
Each visualization approach employs distinct navigation techniques such as scrolling, panning, and zooming, requiring participants to invest time in becoming familiar with

each approach. Once participants became familiar to the approaches, both the Zoomable circle packing and Scrolling baseline methods showed advantages in task completion, although these advantages were not statistically significant. In terms of **efficiency**, specifically task completion time, **no approach** displayed a clear overall statistical advantage.

7. CONCLUSION

To bridge the research gap on effectively visualizing the vertical context of geographic locations, employing a visualization approach with the following features can enhance a better picture of the vertical context of a geographic location:

1. *Grouping every attributes into main categories and subcategories* – Arranging attributes into primary categories and subsequently dividing them into subcategories establishes a structured method, contrasting with the unsorted and unistructural disposition of attributes. This grouping approach contributes to improved effectiveness, ease of use, satisfaction, and enjoyment of the visualization approach.
2. *Arranging attributes of the same attribute category in close proximity to each other* – placing attributes of the same category in close proximity to one another promotes spatial grouping, unlike arranging them along the outer edge of a spiral or in a linear top-to-bottom manner. Such spatial organization contributes to heightened effectiveness, enjoyment, satisfaction, and ease of use in the visualization approach.
3. *Utilizing zooming effects for attribute exploration and smooth transitions between attributes*- A zooming effect is implemented to enhance the focused exploration of individual attributes and zoom-out feature is also applied during transitions between attributes or when moving from one attribute category to another. This replaces the other methods of navigating through attributes using mouse panning, scrolling between tabular data from top to bottom, enhancing effectiveness, enjoyment, satisfaction and ease of use of the visualization approach.

Furthermore, attribute levels within the 60-180 range are not affected in the visualization method for representing the vertical context in geographic locations.

7.1 Limitations and future work

For the user experiment, 18 participants took part, with the majority falling within the 20-40 age range and possessing similar levels of computer literacy and educational backgrounds. A limitation of this study is the relatively small number of participants due to limited time and their homogeneous background. Due to the limited number of participants, a total of 54 data points were recorded, with only three data points available for each attribute category in a given visualization approach. This limited data points resulted in instances where the average values of dependent variables for certain attribute levels exhibited statistical deviations due to occasional extreme performance by individual participants. As part of future work, it would be beneficial to conduct the experiment with a larger and more diverse participant pool for maintaining heterogeneous background. Increasing the number of data points can help eliminate statistical deviations in the average values of dependent variables for certain attribute levels, which may arise from occasional extreme performances by individual participants.

The prototype was designed exclusively for large screen sizes, only suitable for laptops and desktop computers, and not intended for mobile devices such as phones and tablets. This limitation in the research arises from the evolving technology environment, where map-based systems are gaining popularity in geographic information system environments tailored for mobile devices. Therefore, it is advisable to assess the effectiveness of visualization methods specifically tailored for mobile devices.

The key takeaway is that a visualization approach with a rich semantic zooming feature is most effective for representing the vertical context of geographic locations. The implemented zoomable circle packing approach utilizes the D3.js library. Additionally, it is advisable to consider new approaches with zooming features for visualizing the vertical context, such as the zoomable icicle approach[8] and the zoomable sunburst approach[9], as mentioned in the D3.js documentation site.

In this study, three visualization approaches employing distinct techniques have been evaluated. It is recommended to consider the Categorization + Expansion technique for visualizing the vertical context of geographic locations. Using the expansion technique, users can expand and shrink the vertical attributes. An example of this technique is the collapsible tree approach[10] mentioned in the D3.js documentation.

[8] https://observablehq.com/@d3/zoomable-icicle?intent=fork
[9] https://observablehq.com/@d3/zoomable-sunburst?intent=fork
[10] https://observablehq.com/@d3/collapsible-tree?intent=fork

In this research, categorization serves as the primary tool for grouping attributes in three visualization approaches. During the interview section, a few participants mentioned that adding an interactive filtering method for attribute categories would enhance the system. Therefore, conducting an evaluation of the effectiveness of visualization approaches with different filtering methods is recommended as a future extension of the research project.

In this study, we focused on two datasets encompassing administrative, political, geography, weather, and air quality data. However, future studies could enhance their scope by exploring the effectiveness of visualization methods across a wider array of datasets, including ocean data, health data, crime data, and urban data. Additionally, future research could investigate how different datasets contribute to the visualization of the vertical context of geographic locations.

8. GitHub REPOSITORY

The codes created for this thesis are accessible on GitHub. The repository encompasses source codes dedicated to data processing, web application development with data visualization, statistical result analysis, and the datasets generated from the user experiments conducted in relation to the thesis titled "Visualizing the Vertical Context of Geographic Locations."

Repository Name:

Master_Thesis_Visualizing_the_vertical_context_of_geographic_locations

URL:

https://github.com/Prasadmadhusanka/Master_Thesis_Visualizing_the_vertical_context_of_geographic_locations

9. REFERENCES

Andrienko, N., & Gennady Andrienko. (2006b). *Exploratory Analysis of Spatial and Temporal Data : A Systematic Approach*. Springer Berlin Heidelberg.

Anselin, L. (1996). *Interactive Techniques and Exploratory Spatial Data Analysis Interactive Techniques and Exploratory Spatial Data Analysis Digital Commons Citation Digital Commons Citation*. https://researchrepository.wvu.edu/rri_pubs

Bjork, S., Holmquist, L. E., & Redstrom, J. (1999). Framework for focus+context visualization. *Proceedings of the IEEE Symposium on Information Visualization, April*

2015, 53–56. https://doi.org/10.1109/infvis.1999.801857

Bonneau, G.P., Ertl, T., & Nielson, G. M. (2006). *Scientific Visualization: The Visual Extraction of Knowledge from Data*. Springer Science & Business Media.

Bostock, M. (2018b, November 26). *Zoomable Circle Packing*. Observable. https://observablehq.com/@d3/zoomable-circle-packing

Cavaller, V. (2021). Dimensional Taxonomy of Data Visualization: A Proposal From Communication Sciences Tackling Complexity. *Frontiers in Research Metrics and Analytics*, *6*(April), 1–22. https://doi.org/10.3389/frma.2021.643533

Correa, C. (2011). Social Network Data Analytics. In *Social Network Data Analytics* (Issue March 2011). https://doi.org/10.1007/978-1-4419-8462-3

Dall'erba, S. (2009). Exploratory Spatial Data Analysis. *International Encyclopedia of Human Geography*, 683–690. https://doi.org/10.1016/B978-008044910-4.00433-8

Daniel, A., & Gerlanc, M. D. (2023). Package ' *bootES* .' 1–5.

Frhoff, L. (2020). Rethinking the usage and experience of clustering in web mapping. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *12184 LNCS*(2005), 3–22. https://doi.org/10.1007/978-3-030-50020-7_1

Goodchild, M.F. (1987). A spatial analytical perspective on geographical information systems. Int. J. Geogr. Inf. Sci., 1, 327-334.

Goodchild, M., Haining, R., & Wise, S. (1992). Integrating GIS and spatial data analysis: Problems and possibilities]; International Journal of Geographical Information Systems, 6(5), 407-423. https://doi.org/10.1080/02693799208901923

Goodchild, M. F., Guo, H., Annoni, A., Bian, L., De Bie, K., Campbell, F., Craglia, M., Ehlers, M., Van Genderen, J., Jackson, D., Lewis, A. J., Pesaresi, M., Remetey-Fülöpp, G., Simpson, R., Skidmore, A., Wang, C., & Woodgate, P. (2012). Next-generation digital earth. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(28), 11088–11094. https://doi.org/10.1073/pnas.1202383109

Gorte, V., & Degbelo, A. (2022). Choriented Maps: Visualizing SDG Data on Mobile Devices. *Cartographic Journal*, 59(1), 35–54. https://doi.org/10.1080/00087041.2021.1986616

Haining, R., Wise, S., & Ma, J. (1998). *Exploratory Spatial Data Analysis in a Geographic Information System Environment Author (s): Robert Haining , Stephen Wise and Jingsheng Ma Source : Journal of the Royal Statistical Society . Series D (The Statistician), Vol . 47 , No . 3 Published by*. *47*(3), 457–469.

Heath, T., & Bizer, C. (2011). Linked Data: Evolving the Web into a Global Data Space. *Synthesis Lectures on the Semantic Web: Theory and Technology*, *1*(1), 1–136. https://doi.org/10.2200/s00334ed1v01y201102wbe001

Kirby, K. N., & Gerlanc, D. (2013). BootES: An R package for bootstrap confidence intervals on effect sizes. Behavior Research Methods, 45(4), 905–927. https://doi.org/10.3758/s13428-013-0330-5

Kraak, M. J. (2003). Geovisualization illustrated. *ISPRS Journal of Photogrammetry and Remote Sensing*, *57*(5–6), 390–399. https://doi.org/10.1016/S0924-2716(02)00167-3

Lai, P.-C., & Degbelo, A. (2021). A Comparative Study of Typing and Speech For Map Metadata Creation. *AGILE: GIScience Series*, *2*, 1–12. https://doi.org/10.5194/agile-giss-2-7-2021

Listemann, M., Trapp, M., & Döllner, J. (2019). Lens-based focus+context visualization techniques for interactive exploration of web-based reachability maps. *Journal of WSCG*, *27*(2), 83–92. https://doi.org/10.24132/JWSCG.2019.27.2.1

Maceachren, A. M., & Kraak, M. (2018). *Research Challenges in Geo visualization*. *January 2001*.

quest.cgi. (2019). *USE Questionnaire: Usefulness, Satisfaction, and Ease of use*. Garyperlman.com. https://garyperlman.com/quest/quest.cgi?form=USE

Saket, B., Endert, A., & Stasko, J. (2016). Beyond usability and performance: A review of user experience-focused evaluations in Visualization. *ACM International Conference Proceeding Series*, *24-October-2016*, 133–142. https://doi.org/10.1145/2993901.2993903

Srivastava, D. (2023). An Introduction to Data Visualization Tools and Techniques in Various Domains. *International Journal of Computer Trends and Technology*, *71*(4), 125–130. https://doi.org/10.14445/22312803/ijctt-v71i4p116

Wada, K., Wallner, G., & Vos, S. (2022). Studying the Utilization of a Map-Based Visualization with Vitality Datasets by Domain Experts. *Geographies*, *2*(3), 379–396. https://doi.org/10.3390/geographies2030024

Wang, S., Pan, B., Guo, X., Wang, Z., & Peng, Q. (2011). 2.5D focus+context map visualization. *Proceedings - 12th International Conference on Computer-Aided Design and Computer Graphics, CAD/Graphics 2011*, 389–396. https://doi.org/10.1109/CAD/Graphics.2011.43

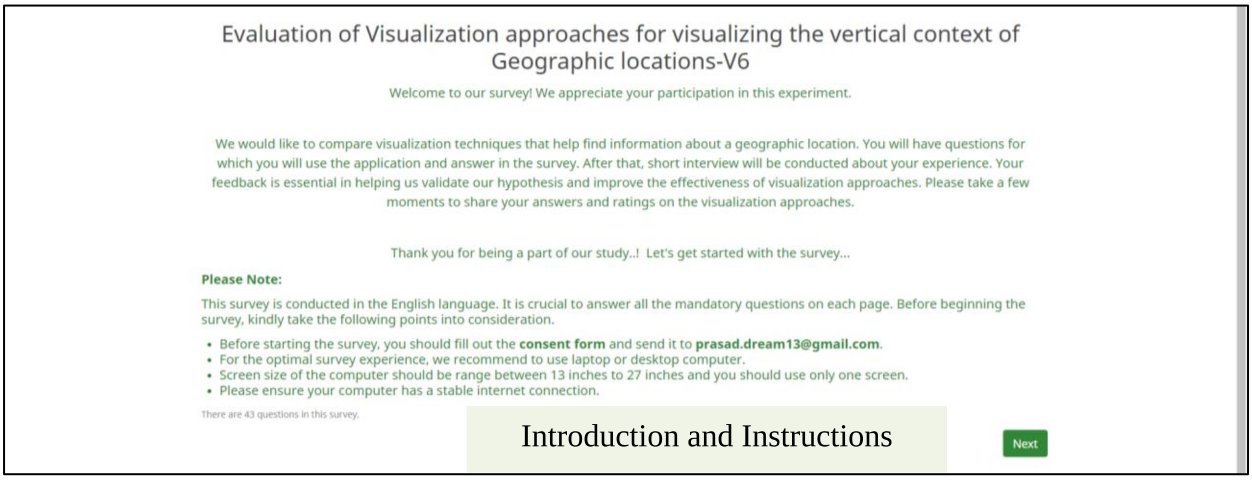
Wang, X., & Zhu, Z. (2023). Context understanding in computer vision: A survey. *Computer Vision and Image Understanding*, *229*, 1–29. https://doi.org/10.1016/j.cviu.2023.103646

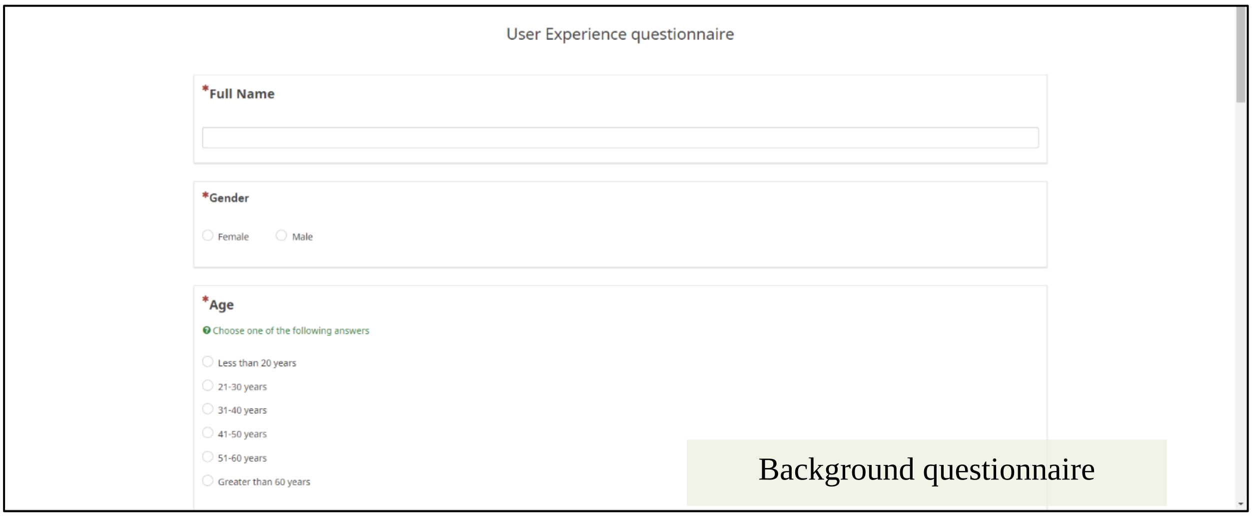
Webster, M. (2018). Definition of context. *Merriam-Webster Online Dictionary*, *January 2005*. http://www.webster.com/cgi-bin/dictionary?context%3E.

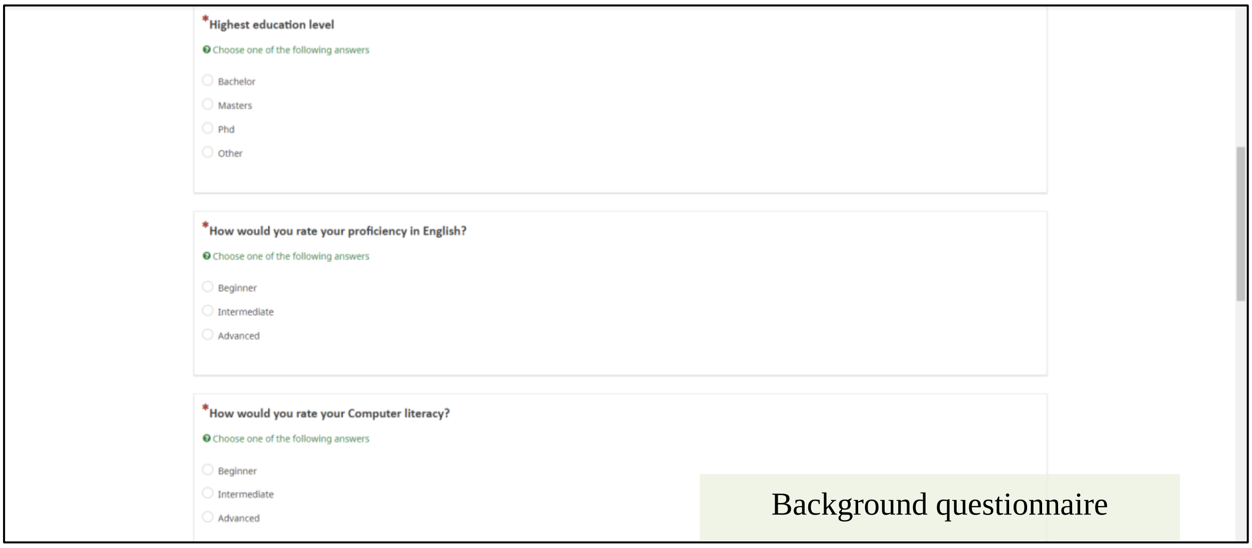
10. ANNEXURES

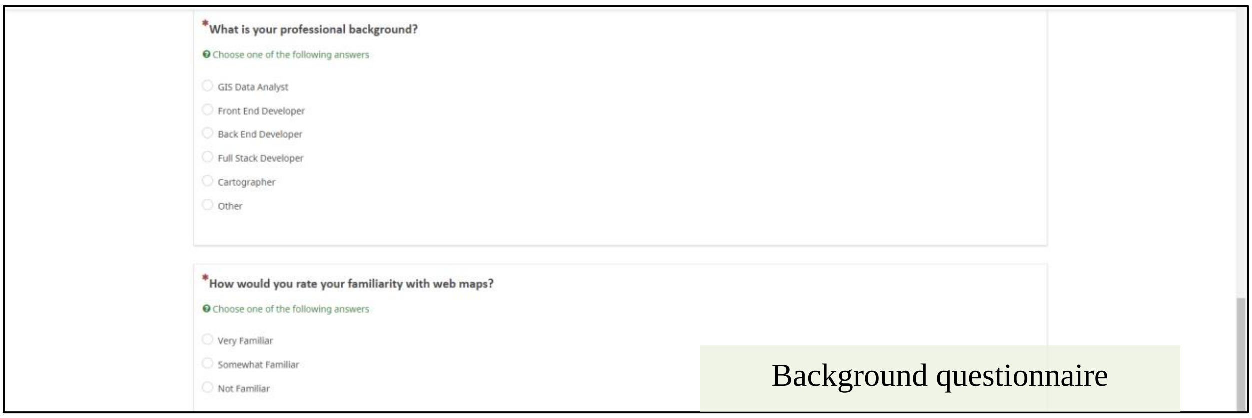
10.1 Annexure I (Experimental material designed using LimeSurvey platform)

For example, the following screenshot images are the experiment materials designed for Participant 6, 12, 18 (P1, P12, P18).









*What is your professional background?

Choose one of the following answers

- GIS Data Analyst
- Front End Developer
- Back End Developer
- Full Stack Developer
- Cartographer
- Other

*How would you rate your familiarity with web maps?

Choose one of the following answers

- Very Familiar
- Somewhat Familiar
- Not Familiar

Background questionnaire

*How would you rate your familiarity with web maps?

Choose one of the following answers

- Very Familiar
- Somewhat Familiar
- Not Familiar

*How would you rate your familiarity with leaflet.js markers and leaflet.js marker patterns?

Choose one of the following answers

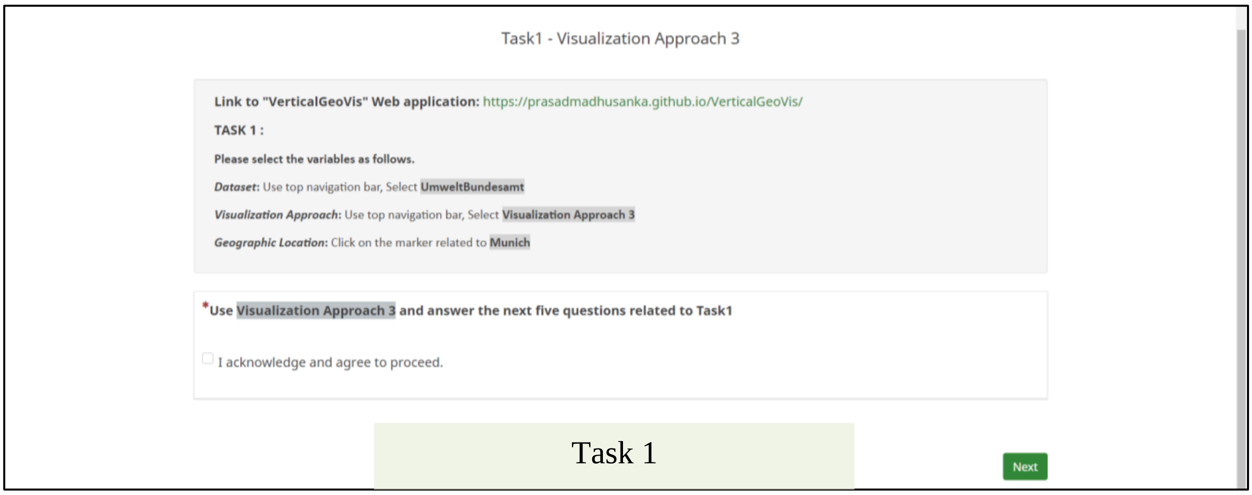
- Very Familiar
- Somewhat Familiar
- Not Familiar

*How would you rate your familiarity with the D3.js Zoomable circle packing Visualization?

Choose one of the following answers

- Very Familiar
- Somewhat Familiar
- Not Familiar

Background questionnaire



Task1 - Visualization Approach 3

Link to "VerticalGeoVis" Web application: https://prasadmadhusanka.github.io/VerticalGeoVis/

TASK 1 :

Please select the variables as follows.

Dataset: Use top navigation bar, Select **UmweltBundesamt**

Visualization Approach: Use top navigation bar, Select **Visualization Approach 3**

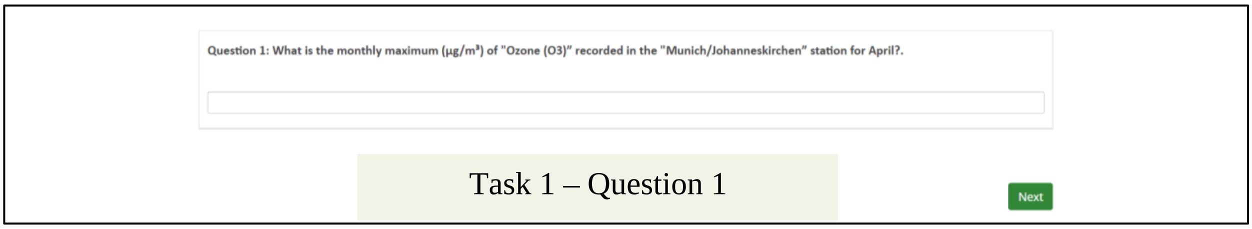
Geographic Location: Click on the marker related to **Munich**

***Use Visualization Approach 3 and answer the next five questions related to Task1**

I acknowledge and agree to proceed.

Task 1

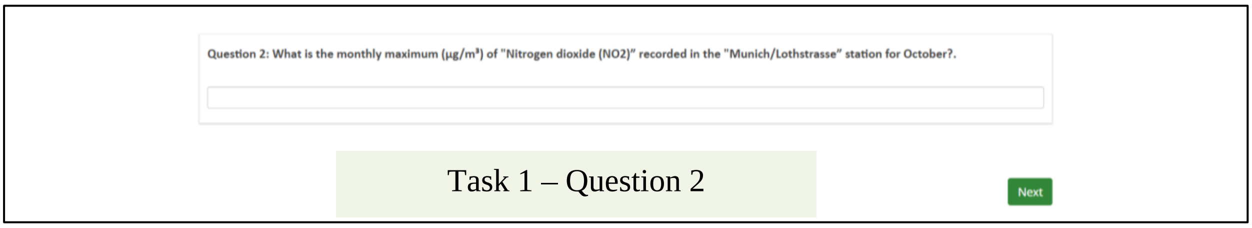
Next



Question 1: What is the monthly maximum (µg/m³) of "Ozone (O3)" recorded in the "Munich/Johanneskirchen" station for April?.

Task 1 – Question 1

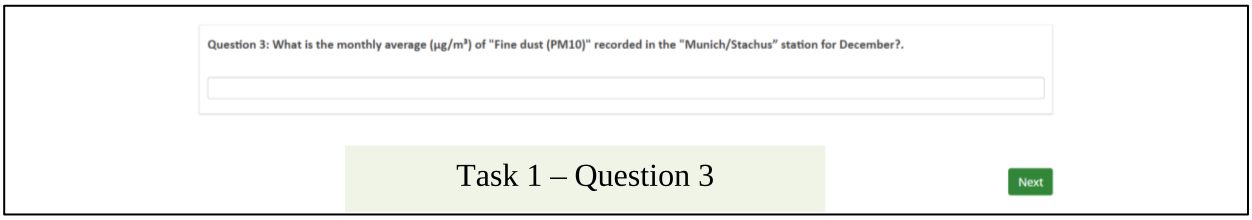
Next

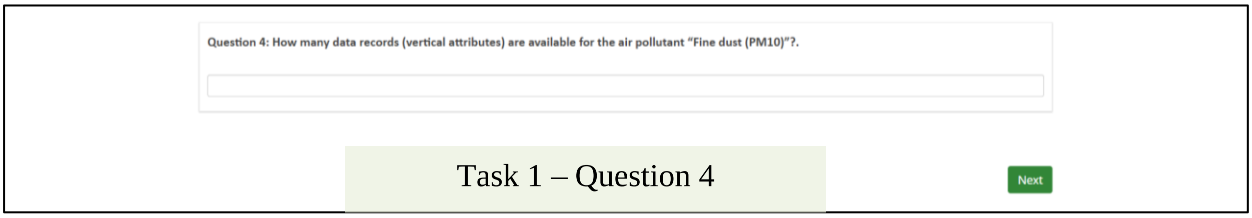


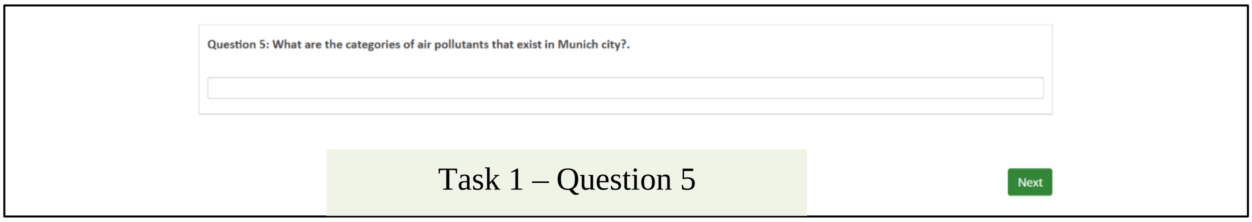
Question 2: What is the monthly maximum (µg/m³) of "Nitrogen dioxide (NO2)" recorded in the "Munich/Lothstrasse" station for October?.

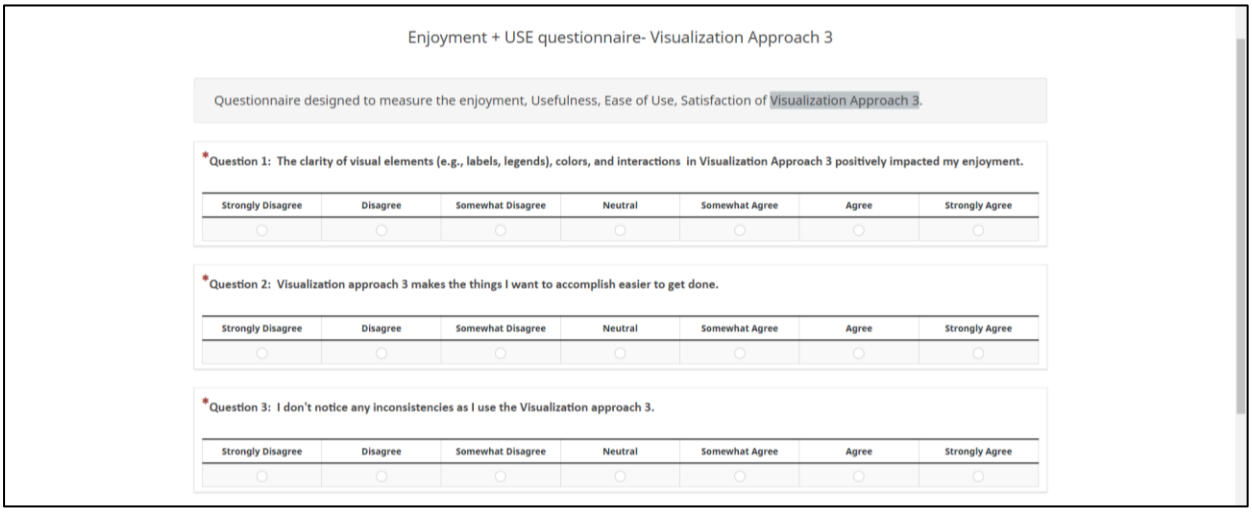
Task 1 – Question 2

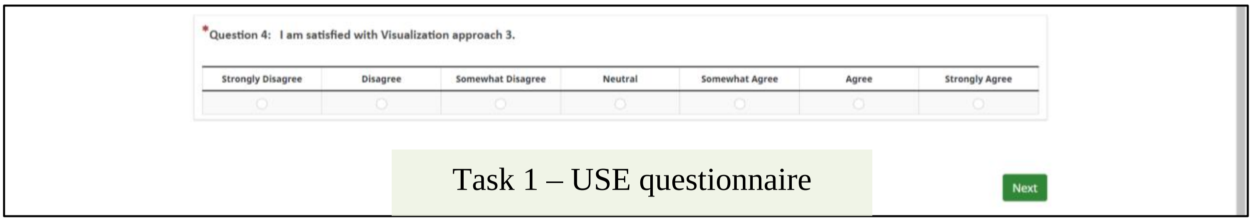
Next

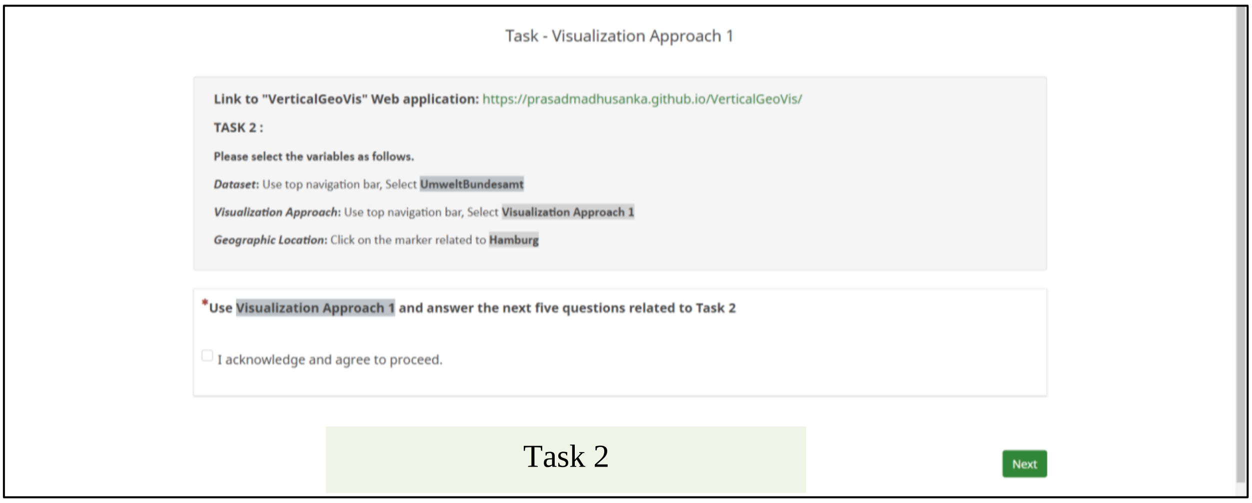

Question 3: What is the monthly average (μg/m³) of "Fine dust (PM10)" recorded in the "Munich/Stachus" station for December?.
Task 1 – Question 3
Next


Question 4: How many data records (vertical attributes) are available for the air pollutant "Fine dust (PM10)"?.
Task 1 – Question 4
Next


Question 5: What are the categories of air pollutants that exist in Munich city?.
Task 1 – Question 5
Next


Enjoyment + USE questionnaire- Visualization Approach 3
Questionnaire designed to measure the enjoyment, Usefulness, Ease of Use, Satisfaction of Visualization Approach 3.
*Question 1: The clarity of visual elements (e.g., labels, legends), colors, and interactions in Visualization Approach 3 positively impacted my enjoyment.
Strongly Disagree
Disagree
Somewhat Disagree
Neutral
Somewhat Agree
Agree
Strongly Agree
*Question 2: Visualization approach 3 makes the things I want to accomplish easier to get done.
Strongly Disagree
Disagree
Somewhat Disagree
Neutral
Somewhat Agree
Agree
Strongly Agree
*Question 3: I don't notice any inconsistencies as I use the Visualization approach 3.
Strongly Disagree
Disagree
Somewhat Disagree
Neutral
Somewhat Agree
Agree
Strongly Agree


*Question 4: I am satisfied with Visualization approach 3.
Strongly Disagree
Disagree
Somewhat Disagree
Neutral
Somewhat Agree
Agree
Strongly Agree
Task 1 – USE questionnaire
Next


Task - Visualization Approach 1
Link to "VerticalGeoVis" Web application: https://prasadmadhusanka.github.io/VerticalGeoVis/
TASK 2 :
Please select the variables as follows.
Dataset: Use top navigation bar, Select UmweltBundesamt
Visualization Approach: Use top navigation bar, Select Visualization Approach 1
Geographic Location: Click on the marker related to Hamburg
*Use Visualization Approach 1 and answer the next five questions related to Task 2
I acknowledge and agree to proceed.
Task 2
Next

Question 1: What is the monthly maximum (µg/m³) of "Ozone (O3)" recorded in the "Hamburg Sternschanze" station for April?.

Task 2 – Question 1

Next

Question 2: What is the monthly maximum (µg/m³) of "Nitrogen dioxide (NO2)" recorded in the "Hamburg Max-Brauer-Allee II (Straße)" station for October?.

Task 2 – Question 2

Next

Question 3: What is the monthly average (µg/m³) of "Fine dust (PM10)" recorded in the "Hamburg Habichtstrasse" station for December?.

Task 2 – Question 3

Next

Question 4: How many data records (vertical attributes) are available for the air pollutant "Fine dust (PM10)"?.

Task 2 – Question 4

Next

Question 5: What are the categories of air pollutants that exist in Hamburg city?.

Task 2 – Question 5

Next

Enjoyment + USE questionnaire- Visualization Approach 1

Questionnaire designed to measure the enjoyment, Usefulness, Ease of Use, Satisfaction of Visualization Approach 1.

*Question 1: The clarity of visual elements (e.g., labels, legends), colors, and interactions in Visualization Approach 1 positively impacted my enjoyment.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

*Question 2: Visualization approach 1 makes the things I want to accomplish easier to get done.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

*Question 3: I don't notice any inconsistencies as I use the Visualization approach 1.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

*Question 4: I am satisfied with Visualization approach 1.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Task 2 – USE questionnaire

Next

Task - Visualization Approach 2

Link to "VerticalGeoVis" Web application: https://prasadmadhusanka.github.io/VerticalGeoVis/

TASK 3 :

Please select the variables as follows.

Dataset: Use top navigation bar, Select **UmweltBundesamt**

Visualization Approach: Use top navigation bar, Select **Visualization Approach 2**

Geographic Location: Click on the marker related to **Berlin**

***Use Visualization Approach 2 and answer the next five questions related to Task 3.**

I acknowledge and agree to proceed.

Next

Task 3

Question 1: What is the monthly maximum (µg/m³) of "Ozone (O3)" recorded in the "Berlin Friedrichshagen" station for April?.

Next

Task 3 – Question 1

Question 2: What is the monthly maximum (µg/m³) of "Nitrogen dioxide (NO2)" recorded in the " Berlin Wedding" station for October?.

Next

Task 3 – Question 2

Question 3: What is the monthly average (µg/m³) of "Fine dust (PM10)" recorded in the "Berlin Schildhornstraße" station for December?.

Next

Task 3 – Question 3

Question 4: How many data records (vertical attributes) are available for the air pollutant "Fine dust (PM10)"?.

Next

Task 3 – Question 4

Question 5: What are the categories of air pollutants that exist in Berlin city?.

Next

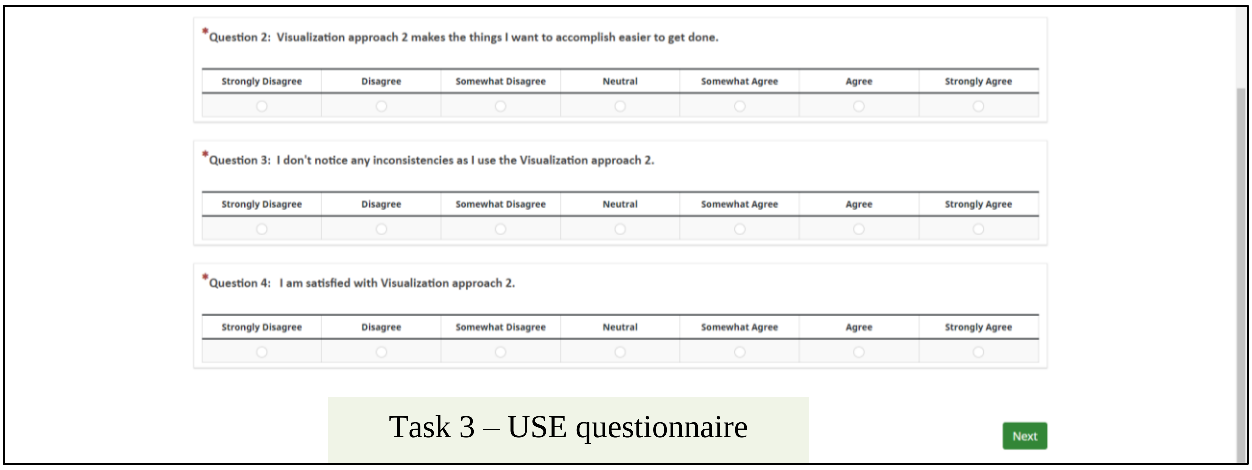
Task 3 – Question 5

Enjoyment + USE questionnaire- Visualization Approach 2

Questionnaire designed to measure the enjoyment, Usefulness, Ease of Use, Satisfaction of Visualization Approach 2.

***Question 1: The clarity of visual elements (e.g., labels, legends), colors, and interactions in Visualization Approach 2 positively impacted my enjoyment.**

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
○	○	○	○	○	○	○



*Question 2: Visualization approach 2 makes the things I want to accomplish easier to get done.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

*Question 3: I don't notice any inconsistencies as I use the Visualization approach 2.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

*Question 4: I am satisfied with Visualization approach 2.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Next

Task 3 – USE questionnaire

Participants's Interview

*Question 1: Considering the three visualization approaches you've interacted with, could you please rank them in order of preference based on which one you found most effective in helping your answer the questions?.

Double-click or drag-and-drop items in the left list to move them to the right - your highest ranking item should be on the top right, moving through to your lowest ranking item.
Please select at most 3 answers

Available items
Visualization Approach 3
Visualization Approach 1
Visualization Approach 2

Your ranking

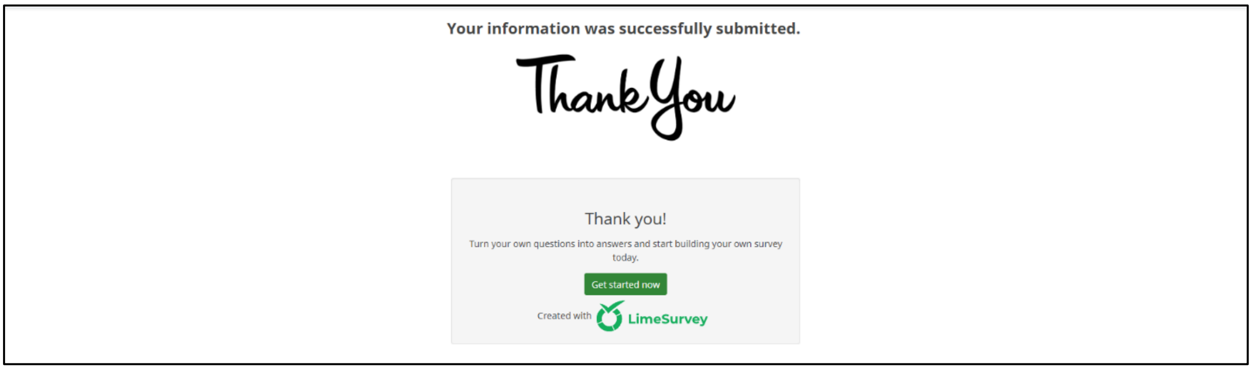
*Question 2: Could you please provide reasons for ranking them.

Participants Interview questions

Question 3: Do you have any suggestions regarding this Web Application for further improvements?.

Submit

Participants Interview questions



Your information was successfully submitted.

Thank You

Thank you!

Turn your own questions into answers and start building your own survey today.

Get started now

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