2020 24th International Conference Information Visualisation (IV) | 978-1-7281-9134-8/20/$31.00 ©2020 IEEE | DOI: 10.1109/IV51561.2020.00067

# RoseTrajVis: Visual Analytics of Trajectories with Rose Diagrams

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***Abstract*—In this paper we propose RoseTrajVis, a visual analytics system for studying trajectories using rose diagrams, inspired in a classic visualization technique for aggregating data. The rose diagram is composed of sectors (petals) that aggregate trajectories given their direction and show their speeds within an area around a point in a map. It also includes colored arrows on the border that point to the origin and destination of the trajectories and show their average speed. RoseTrajVis enables users to place rose diagrams over a map view and interact with them by applying time, speed and distance to origin/destination filters, and by adjusting the aggregation radius, allowing the visualization of commuting patterns in a city. We prepared a prototype of RoseTrajVis with taxi data, and evaluated the completion times and errors of users carrying out trajectory analysis tasks, and also collected feedback from a domain expert. Results revealed that completion times varied with task complexity, being longer for tasks requiring exploratory analysis of the trajectories on a map, and that almost no errors were made by users. The expert mentioned that RoseTrajVis provides an innovative way of analysing aggregate trajectories and has the potential to be useful in several professional areas.**

***Index Terms*—visual analytics, trajectories aggregation, rose diagrams, taxi trajectories.**

## I. Introduction

It is common for organizations to have large amounts of data that exceeds human processing capacity, and it is necessary to aggregate and filter them to enable the discovery of patterns and trends [1]. The visualization and interaction with aggregated data are important aspects to help decision makers and domain users, being at the core of the analytical data visualization [2].

The increasing usage of position tracking technologies has enabled the collection of large volumes of data, representing entities mobility, such as people and vehicles. Nowadays, the study of human trajectories is fundamental to improve the lives of citizens, and is used, for example, by expert analysts in planning urban tasks. Hence, the study of techniques to visualize trajectories is a timely and relevant challenge.

Large trajectory datasets can cause visual and computational problems in most approaches for interactive exploration of trajectories, such as lines on a map or in a space time cube (STC) [3]–[6]. These techniques present several performance limitations related to data processing and rendering work, making the analysis of data a time-consuming and tiresome task and usually present cluttering and overlapping of the symbols, obstructing information perception and analysis of patterns. Two main approaches have been proposed to solve the visual effectiveness problem. One, is to resolve the overlap by density mapping or repositioning or shifting data points [5]. Another approach is to reduce the data size by combining visual approaches with computational techniques like data abstraction (or generalization), which includes clustering, filtering, smoothing and data aggregation approaches [7].

In our work, the goal of the analysis is to understand commuting movements of the population in a city, where and when there is more traffic and where the drivers came from and went to, to help improve and reorganize the traffic in a city. To address these challenges, we designed RoseTrajVis, a system that integrates a web application and services, to give decision makers the possibility to analyse trajectories on a map by placing and interacting with graphics inspired in rose diagrams [8]–[10] that aggregate trajectories information in a geographic area and support several filtering mechanisms. Rose diagrams, also called polar area diagrams, are useful for showing directional data and supporting the analysis of cyclic temporal patterns of event occurrences in different places [11]. These diagrams are composed of sectors (petals) radiating from a common center, all with the same angular size but with different lengths or areas. The area or length of each sector represents the numeric value associated with each position in the cycle. The cycle could be temporal (e.g., daily or yearly) or of another nature (e.g. directions).

Applying the rose diagram to trajectory data, the petals aggregate trajectories given their direction and show their speeds within an area around a point in a map. The largest petal is the one whose direction aggregates more trajectories and the largest colored region within each petal represents the most common speed. Users can interact with the rose by applying time, speed and distance to origin/destination filters and by adjusting the aggregation radius. We also placed arrows on the border of rose diagrams, pointing to the origin and destination of the trajectories. To our knowledge, RoseTrajVis offers innovative ways of analysing trajectories and contributes to increase the knowledge in the area of visual analytics.

The paper is structured as follows: Section II presents the related work; Section III describes RoseTrajVis system; Section IV provides the design, results, and discussion of a user

2375-0138/20/$31.00 ©2020 IEEE
DOI 10.1109/IV51561.2020.00067

study, including expert feedback; and Section V presents the conclusions and ideas for future work.

## II. Related Work

**Rose diagrams**: The visualization presented in our work is inspired by Florence Nightingale's polar area diagrams [10], also referred to as rose diagrams, used to represent the mortality during the Crimean War. Each sector of the rose diagram corresponds to a month of a year and the area is proportional to the number of deaths. The segments of each sector represent the causes of deaths. One of the most common uses of rose diagrams is in the analysis of wind data in meteorology [8] and also in infrastructure planning decision. In these approaches rose diagrams are drawn on a map in specific places to represent aggregates, such as counts of spatial events.

In terms of infrastructure planning, the ARO system seeks to facilitate the task of guiding the runways of an airport, using rose diagrams to allow the analysis of the prevailing winds, in particular, if they are favourable to take-off and landing of airplanes [12]. In another work, the rose diagrams were useful to characterize the prevailing winds in five places, allowing to decide on the installation of windmills [13].

Bak et al. [14] uses the rose diagram visualization technique to represent individual events rather than derived aggregates and the sectors correspond to hourly intervals of a day. The rose diagrams are drawn on a map to explore spatial and temporal distribution of stops durations of public transport in Helsinki.

TrajGraph [15] is a visual analytics system to study mobility patterns based on graph modelling and uses rose diagrams to visualize the temporal changes of the information on a region. Using each sector of the rose diagram to represent a two-hour window, one day is shown in 12 sectors in the circle. The diagrams are used to examine the time varying information and find a time period of interest to conduct further study. It is a different approach from the one proposed by RoseTrajVis.

**Visualization of trajectory data**: A large number of visualization approaches have been proposed to explore trajectory data [11]. Large dimensions of trajectory datasets can cause serious problems for most visualization techniques, namely, presenting cluttering and overlapping of the symbols, obstructing information perception and analysis of patterns (visual effectiveness problem) [5], [16]. Common approaches to solve these problems are filtering [17] and aggregation [7].

Aggregation is an instrument to deal with large datasets enabling an overall view of the spatial and temporal (ST) distribution of multiple movements. Several approaches to aggregate movement data can be found in [18], [19] and also in [20]. We are going to describe the most relevant approaches to visualize the results of aggregation of movement data, namely for spatial and ST aggregation.

Common techniques to **visualize aggregated movement data** are flow maps [7], [21], [22] and origin-destination (OD) matrices that represent summarized movements among places [23]–[25]. Andrienko et al. [26] propose an approach to aggregate OD flows that share a common origin or destination. This approach reduces the data dimensionality and enables a visual representation using flow diagrams rather than flow lines positioned at the places of trip origins or destinations and show the counts of trips to/from different directions and distance ranges. A design variant of proposed flow diagrams is rose diagrams that use colors of the sectors to distinguished the distances ranges (yellow, orange and red for short, medium and long distances). The sectors' lengths represent the flow magnitudes. The sectors could be divided proportionally in segments to represent the different distance ranges or the division is applied to the lengths of sectors. The temporal variation of the trip distribution is studied using temporal clustering of spatial situations. This is a different approach from the one proposed by RoseTrajVis.

Another common approach consists of using 2D histograms or heatmaps, to show the frequency of a certain type of spatial event. The colouring of these maps can, in an intuitive way, transmit the notion of which areas are more often used [11], [27]–[29]. Similarly, density maps can also be considered as an alternative for aggregated trajectory visualization. These maps consist of an aggregate overview of the data, where wider density fields correspond to larger amounts of data, and their colour and saturation variations may represent the instant in time or the variation of an attribute, for instance, the average speed of the moving objects [30], [31].

When considering time, the data is analysed in space and time intervals. For instance, the space is divided into compartments and the time span of the data into intervals. An aggregated statistic is computed for each compartment and each interval and represented over time. A common technique to represent ST aggregation results is combining the previous methods (e.g. flow maps, OD matrix) with animated maps, where one step of the animation corresponds to one time interval in the aggregated data. Another way to represent the passage of time is using small multiple maps showing the variation of movements by specific hourly intervals. Another alternative to visualize ST aggregates consists in the use of additional tables and graphs, inside or outside the map, to clearly represent the variation of attributes during time [7], [32], [33], for instance, suggest the representation of aggregated movements with complex symbols, similar to tables.

Our work follows the alternative that uses additional graphs, in this case rose diagrams, drawn over a map with trajectories to represent, in an aggregated form, information of the trajectories, and expands the approach taken on [34] by optimizing filtering mechanisms and supporting larger datasets of trajectories to enable more complex visual analytics tasks.

## III. RoseTrajVis System

In this paper we use the mobility traces of taxi cabs of Rome, Italy as an example dataset. This dataset contains GPS coordinates of approximately 320 taxis collected over 30 days. Our aim is to use this data for visual analytics, for example, to study of commuting movements of the population in a city, where and when there is more traffic and where the drivers came from and where they go, to improve and reorganize the traffic in a city. This goal involves some design requirements for a visual analytics approach in order to allow the user's analysis work:

- Interactive visual analytics: users should be able to analyse trajectories on a map, by placing and interacting with rose diagrams. These diagrams can be created freely at any point on the map, and the user can create several at different points, allowing the analysis and comparison of trajectories at locations s/he considers relevant;
- Intuitive and meaningful visualization: the graphic elements of the rose diagrams must be able to show data about the aggregated trajectories, for instance, the total number of trajectories, the radius of aggregation of the rose, the intervals of hours of occurrence, the speed of circulation in the area, the directions of origin / destination and the average speed;
- Interactive visualization: users should be able to interact and manipulate the rose diagrams created on the map, through filters to adjust the parameters applied to each rose. These changes must be able to be made individually or jointly, so that the user can quickly analyse comparatively two or more points on the map, under the same conditions.

To address these requirements we developed RoseTrajVis, a visual analytics system that integrates a web application and services supported by a geographic database to give the decision maker the possibility to analyse trajectories on a map by placing and interacting with rose diagrams that aggregates trajectories information in a geographic area and supports several filtering mechanisms. The following sections focus on the most important components and features of RoseTrajVis.

The system has four main components: web services written in PHP; a web application in JavaScript that allows the placement of rose diagrams on a map; a JavaScript library with the data model and management functions of rose diagrams; and a geographic database in PostGIS. The web services support the web application, offering functionalities such as reading GPS Exchange Format (GPX) file trajectories, loading data to the geographic database, and selecting data. After loading a GPX file, the trajectories, names, start and end dates of the points are listed, and a map with the bounding boxes of the selected trajectories is shown.

The RoseTrajVis web application (see Figure 1) is the main component of the system from the point of view of the user, behaving as a client of the geographic database and the library. The application interface is dominated by a map with the previously selected trajectories, and the user can choose points in the map where s/he wants to create rose diagrams to aggregate and analyse the trajectories that are near those points.

The creation of a rose is done by clicking the right mouse button on a point on the map, drawing a marker and a circle with the area of aggregation. Initially, the radius of aggregation is set to 100 meters and can be changed later. When a marker is placed on the map, the web application selects all the trajectories that intersect the circle of the rose aggregation area. To know in which petal the trajectory belongs to, it is calculated the first and last point of the intersection of each trajectory with the circle. Once the intersections with the circle are obtained, the web application uses the rose library to draw the graphic elements of a rose, such as the petals and speed scale, which is placed next to its marker.

**Trajectories aggregation with rose diagrams**: the web application allows the user to change the properties of each rose individually, such as the radius of trajectory aggregation or time filters, for example, from 100 to 200 meters radius and consider only trajectories in the morning. However, to facilitate comparison of the data shown on several diagram roses, it is also possible to control all roses simultaneously, especially on a map that contains several strategic locations to analyse.

Figure 1 shows a scenario where three markers were created on the map, previously loaded with taxi trajectories in Rome. Each trajectory is represented in a different color, assigned randomly in the loading phase of the data. Colors of the trajectories assume no meaning apart from the differentiation function. Each marker is created by clicking the right mouse button on any area of the map and a gray aggregation area is drawn around the marker. This area delimits the space where trajectories are analysed, and those that do not intersect the gray area are ignored. Beside each marker appears a box containing the corresponding rose diagram. The number displayed in the upper left corner of the rose diagram box represents the corresponding marker number. In the box header there are three distinct buttons, from left to right: the selection button, the pin button, and the close button. The selection button is used to indicate whether the rose diagram can be modified based on the filtering settings, since only selected roses can be changed. The pin button allows to fix the position of the rose diagram on the map, which prevents it from being dragged with the mouse. The close button is used to delete the rose box, along with the corresponding marker. The rose diagram has a grid with a relative occurrence scale, which adjusts according to the maximum number of trajectories that a petal can contain. Each scale's value is associated with one of the circles on the rose grid, with the scale growing from the circle near the center to the outer circle.

Each petal drawn in the rose represents three distinct characteristics:

- Direction: represents the direction of entry of the trajectories when intersect, for the first time, the aggregation circle of the rose marker;
- Length: represents the total number of trajectories aggregated in the petal in relation to the total trajectories presented in the PATHS field at the bottom of the rose. When a petal reaches the circle of 100% of the scale, it means that the petal has all the trajectories that intersect its aggregation area;
- Speed: colors used in petals represent trajectories speeds when they intersect the aggregation circle. The speed scale is based on one Color Brewer diverging scale [35] and is located on the bottom of the RoseTrajVis interface. The petals are proportional divided into subsectors representing the number of trajectories to the different speeds ranges. The sum of the number of

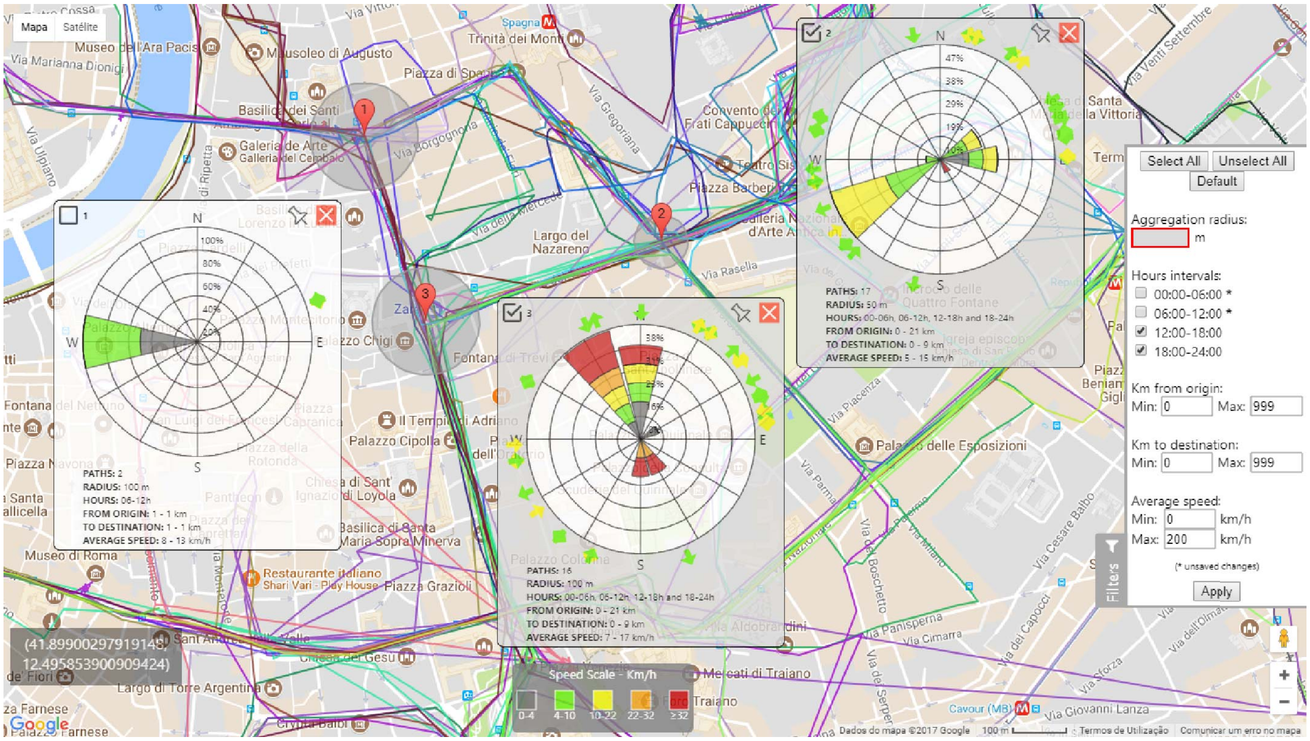


Fig. 1. RoseTrajVis system for trajectories analysis.

trajectories presented in each sub-sector, makes the total of trajectories aggregated by the petal. Although it is not visible in the rose diagrams shown in Figure 1, if the user leaves the mouse over a sub-sector of a petal, is shown a tooltip with the corresponding total of trajectories.

The outer border of the rose diagram contains arrows representing the direction of origin and destination of each trajectory. The orientation of the origin arrow is defined by the direction that points from the beginning of a trajectory to the marker of the rose diagram. The orientation of the destination arrow is given by the direction of the marker to the last point of the trajectory. The color of each pair of arrows represents the average speed of the corresponding trajectory, while the color in the petals corresponds to the speed when the trajectory intersects the area of aggregation of the rose. With this double color coding, a decision maker can analyse if around a point on the map there is a big difference in speeds compared to the complete trajectories, by comparing the dominant colors of the petals and the arrows of origin and destination.

Finally, the footer of the rose diagram contains information about the parameters of the rose and the aggregated trajectories. The first three parameters, PATHS, RADIUS and HOURS, show the total number of trajectories that intersect the rose aggregation area, the radius of aggregation and the possible time intervals allowed in the visualization, respectively. The last three fields, FROM ORIGIN, TO DESTINATION, and AVERAGE SPEED, represent the minimum and maximum relative to the distance in km to the origin/destination (distance between the marker and the first/last point of the trajectory) and the average speed in Km/h, respectively.

**Filters panel and inspector**: the application's dashboard is located on the right side of the RoseTrajVis interface, as shown in Figure 1, and allows to set and change time, speed and distance to origin/destination filters and adjust the aggregation radius. In the example of Figure 1, three rose diagrams were created at different positions on the map. Roses 2 and 3 are selected, which is evidenced by the gray background color of the boxes and the check mark of the selection button in the upper left corner.

When the user creates a new marker on the map, the rose created next to the marker takes the values that are defined in each of the fields in the filter panel. Creating new roses with invalid parameters causes an error message. The application of the filters is subject to the use of the button Apply, which motivated the notification of unsaved changes. Whenever roses are selected, and there are changes in filters relative to those applied to roses, a * symbol is displayed in front of the field, such as signalling that the value has changed, but has not been applied. If the parameters applied to the roses are again defined or the Apply button is used, the notification disappears. For the convenience of the user, two buttons (Select All and Unselect All) were created to quickly mark/unmark all the roses presented on the map. Changing the parameters of roses only occurs, if they are selected.

Figure 1 shows the Inspector functionality in the filter panel. Whenever a rose is selected, the filter panel adjusts the various fields to the values that are set on the selected rose. If any inconsistency is found, a red border is placed and the value of the field is removed from the filter panel. The incoherence disappears with the unmarking of one or more roses that are generating the conflict or simply with the application of a common value to the field that has the inconsistency. Considering Figure 1, it can be observed that the radius of aggregation of roses 2 and 3 is different, which explains the red notification of incoherence of values. For time intervals, if we mark rose 1, the two first hours intervals would be signalized with a gray background, since they are defined but not yet applied to roses 2 and 3. The incoherence signalling of the time intervals checkboxes is slightly different due to style manipulation limitations for this type of field.

## IV. User Study

We conducted a user study to evaluate the ease that users have in analysing scenarios of information overload in a map, using rose diagrams in RoseTrajVis, and also to assess the level of usability through the SUS method [36]. We also interviewed an expert in transportation urban planning. This section describes the participants and methodology used, followed by the results and their discussion.

**Participants, tasks and methodology**: a total of 21 participants volunteered for the study (10 female), with ages between 17 and 27. Most participants had no experience with analysis of trajectories in map applications and only 3 had previously used trajectory analysis applications on mobile devices.

The study consisted of four types of tasks (questions), preceded by an initial questionnaire, an explanation of the concepts and a training session. Each question type corresponds to a plausible and frequent trajectory analysis task, namely:

- SEPE: Select the petal of the rose diagram with the highest number of trajectories and speed or the petal with the highest speed;
- SEMA: Select the marker on the map that corresponds to the rose diagram shown;
- SERO: Select, among several, the rose diagram that corresponds to the marker shown on the map;
- INSE: Analyse a certain area with trajectories on the map, delimited by dashed lines, and indicate the location where trajectories verify a specific requirement, such as the location where more vehicles pass between 18h and 24h or with the most distant destination.

To guide the user, INSE questions were accompanied by a tip, such as "Put rose diagrams in places that you think are pertinent to answer the question". For each question type, there were two associated scenarios in order to test learning effects.

Each participant performed the same tasks, which were randomly reordered at the beginning of each test. During the conduction of the tasks, RoseTrajVis automatically recorded question id, question order, errors, task completion time (in seconds), whether the question was answered or skipped, and date and time of the answer. To study the interaction strategies followed by the participants and the differences between them, it also captured a recording of the screen. After completing the tasks, participants were requested to fill out a questionnaire with 10 questions from the System Usability Scale (SUS) [36] to measure the application usability. An optional comments and suggestions field was also provided, so the participants could freely share their opinions.

**Results and discussion**: we applied the Shapiro-Wilk test to task completion time and task errors, and in both cases the normality assumption could not be accepted ($W = 0.933$ and $W = 0.198$, respectively, $p \ll 0.001$). Therefore, non-parametric tests were considered in the following comparisons.

*Task completion time:* the median varied from 25.2 s in SEPE to 115.5 s in INSE, with SEMA having a median of 68.5 s and SERO 85.0 s (see Figure 2). A Friedman test revealed strong evidence that the distributions were different ($Q = 85.286$, $df = 3$, $p \ll 0.001$), thus we conducted 6 post-hoc comparison tests and adopted a significance level of 0.008, due to the Bonferroni correction. The results of Wilcoxon signed-ranks tests showed significant differences for all pairs of question types ($1 \leq V \leq 903$, $p \ll 0.001$), except between SEMA and SERO ($V = 245.5, p = 0.010$).

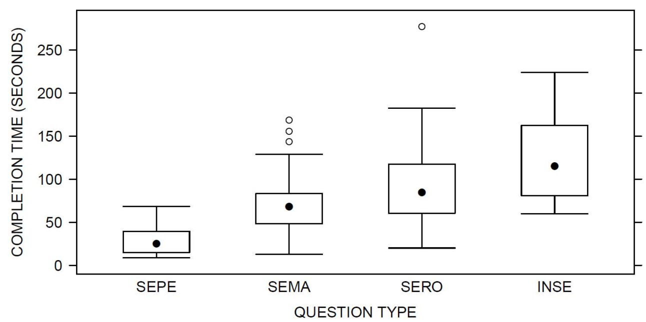


Fig. 2. Task completion time by type of question.

Regarding possible learning effects due to the nature of the repeated measures design, we conducted Wilcoxon signed-ranks tests on scenario order for each type of question (see Figure 3), which revealed no significant differences ($94 \leq V \leq 146, p \geq 0.303$). Additionally, a Friedman test on question order did not provide significant evidence that the distributions were different ($Q = 6.349$, $df = 7$, $p = 0.499$).

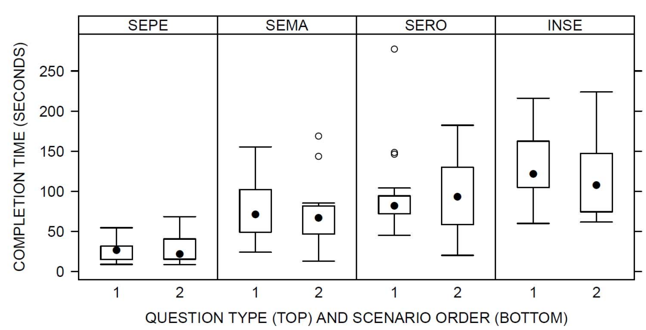


Fig. 3. Task completion time by scenario order per type of question.

In SEPE tasks, participants focused on the rose diagram and were not required to look at the map, which explains the shortest completion times. In SEMA and SERO tasks, both the rose diagrams and the map had to be analysed and related to each other, thus requiring higher cognitive load, incurring in 43 s and 60 s, respectively, of additional time. This suggests that the rose diagram, by itself, takes about 35% of the time to execute the SEMA and SERO analysis tasks.

During the design of the experiment, we purposely created SERO scenarios to raise doubts about the relevant petals and the number of trajectories involved, to make the tasks harder compared to SEMA tasks, but the difference of 16.5 s between the medians was not statistically significant. A possible explanation could be in a problem that was reported by participants regarding SEMA tasks: often, similar colors (chosen randomly) were used to represent different trajectories on the map, which led to more time being spent on color differentiation than on analysing the elements of the roses.

Finally, as expected, INSE tasks had the longest completion times, since they require a more elaborate workflow: participants had to engage in an exploratory analysis of the trajectories on a map, place (and configure) multiple rose diagrams in key places, instead of processing static scenarios. The additional cost was at least 30 s, or about 25% of the total time, compared to SERO tasks.

*Errors:* the number of times a participant clicked on an interface element that did not match the correct answer was mostly zero, regardless of the type of question (see Figure 4).

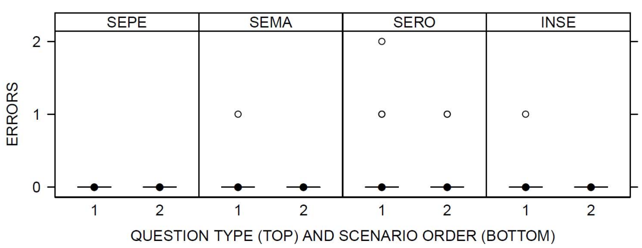


Fig. 4. Errors by scenario order per type of question.

In a somewhat surprising and positive way, the exploratory analysis required in INSE tasks did not increase the number of errors relative to the other, simpler and faster, types of tasks.

*Usability:* regarding the SUS questionnaire, the scores obtained from the participants' answers were interpreted using an adjective rating scale [36] and the results were: 14 Best Imaginable, 6 Excellent, and 1 Good, suggesting that the system was easy to use.

*Interaction strategies in trajectories analysis:* the interaction strategies followed by the participants showed differences and this was verified in INSE questions. A majority of the participants preferred to create the rose diagram with the default parameters and apply the filters later instead of adjusting the filters before the creation of the diagram. One reason could be related with the time that each participant spent in exploring the system in the training session and also the filter panel evidence in the interface.

Two features that were almost never used by the participants were the buttons Select All/Unselect All to quickly mark/unmark all the roses on the map interface, respectively. Most participants chose to mark/unmark one by one instead of using these buttons. One reason pointed by the participants about the workflow for adjusting the properties of the roses was that the buttons were not sufficiently clear about their function.

Finally, some participants preferred to make filter adjustments, rather than looking directly at the information at the bottom of the rose diagram. This was recorded, for example, in INSE questions that asked to mark the area where vehicles with the most distant destination passed. The participants ended up using the information shown at the bottom of the rose diagram and answered the question successfully. These occurrences may be related to the fact that the information shown at the bottom does not have a title that clarifies their relation with the trajectories aggregated by the rose diagram.

*Domain expert feedback*: to understand the applicability and to learn when RoseTrajVis is valuable to domain users, we interviewed a transportation urban planning expert. The first part of the meeting consisted of a practical demonstration of the system and after that we obtained feedback based on a scenario of analysis of bus routes in a city.

The expert considered the system developed with regard to the planning and management of bus routes innovative and useful. He suggested the inclusion of a component to produce text-based reports with summaries of the rose diagrams shown on a map, so that the interpretation of the system is not dependent on the familiarization with the graphical components of the interface. He also mentioned the importance to analyse individual trajectory properties *inside* the aggregation area of strategically placed rose diagrams, namely the average speed and distance travelled, to study alternative routes for buses. The flexibility of setting parameters was one of the most appreciated aspects, since the system that his company uses to monitor their buses, does not allow the reconfiguration of certain filters. However, it was pointed out that it would be useful to freely define time intervals, for example, peak times. Finally, the possibility of using RoseTrajVis with real time data was suggested for future work, as it would allow the development of traffic alerts, which, in turn, would facilitate the redirection of buses to faster alternate routes.

## V. Conclusions and Future Work

In this paper we presented the RoseTrajVis system that allows the analysis of aggregated information about trajectories using rose diagrams. The user can analyse the direction and speed of the trajectories that pass near desired locations on a map, as well as interact with the rose diagrams by adjusting the aggregation radius and by defining time, speed, and distance to origin/destination filters.

A user study with RoseTrajVis revealed it was easy to use and that tasks focused only on the rose diagram took about one third of the time of tasks with static scenarios in which both the rose diagrams and a map had to be analysed and related to each other. The longest completion times were recorded in tasks that required the exploratory analysis of the trajectories on a map and placing (and configuring) multiple rose diagrams in keyplaces. Regardless of the task, users made almost no errors. An expert mentioned that the system provides a useful way of analysing aggregate trajectories regarding the planning and management of bus routes.

Regarding future work, it is important to further assess the usefulness of RoseTrajVis in real scenarios, by working with other trajectory datasets, for instance with real time data, and by collecting more feedback from domain experts, especially suggestions of new features. Currently, we are considering more filters for aggregating trajectories, such as custom time intervals, improvements to origin/destination arrows to control overlapping, and the possibility to analyse trajectories inside the aggregation area. Finally, we have plans to support multiple rose diagrams for the same marker on the map, with different filters applied, to facilitate the analysis of commuting movements of a population in a city.

## ACKNOWLEDGMENT

This work was supported by FCT (Portuguese Science and Technology Foundation) through founding of LASIGE Research Unit, ref. UIDB/00408/2020. The authors are also thankful to the volunteers that participated in the user study.

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