BACHELOR

An Interactive Web-Based Visual Analytics Tool for Detecting Strategic Eye Movement Patterns

Timmermans, Neil

Award date:
2019

Link to publication
An Interactive Web-Based Visual Analytics Tool for Detecting Strategic Eye Movement Patterns

Neil Timmermans
Technical University of Eindhoven
Eindhoven, The Netherlands
N.N.Timmermans@student.tue.nl

ABSTRACT
Eye movement data contains spatial and temporal information, typically recorded by tracking the eyes of several people. The immense flood of data demands for a visual analytics tool that provides a condensed view on the data with the goal to identify strategic eye movement patterns. These patterns can be useful to detect visual problems or design flaws in the displayed stimuli with the goal to improve them. In this Bachelor End Project we describe an interactive and web-based visual analytics tool combining linked visualization techniques, algorithmic approaches, and the perceptual strengths of the human observer with a special focus on detecting hierarchical scanning behavior in eye movement data. To illustrate the usefulness of our concept we apply it to real-world eye movement data and finally, discuss scalability issues and limitations.

KEYWORDS
Eye tracking, information visualization, visual analytics

1 BACHELOR END PROJECT
The Bachelor End project (BEP) is the final project of the students major, and an assessment of the academic proficiency for the Technical University of Eindhoven Bachelor programs. The BEP is an individual project of 10 ECTS, and can be performed in one quartile, or spread out over two quartiles. During the BEP, students demonstrate that they can analyse a perceived problem in the field of their major and that they can communicate the set-up and findings of the research both in a presentation as well as in a written report. The course teaches students to individually perform research on a specific problem. Students are supervised by an academic member of the Technical University of Eindhoven. This BEP was done for the major of Data science at a Bachelor level. The project was within the Algorithms and Visualization sub department, within the Mathematics and Computer Science department, of the Technical University of Eindhoven under the supervision of prof Ir. Dr. M. Burch. The BEP was

Figure 1: The graphical user interface consists of several linked views: Loading data and parameter changing functionality (left), the stimulus view (center), and the strategic eye movement pattern view (right) with details-on-demand (right, lower part).
formed with the goal of creating a web hosted tool where users could upload their own data from movement, with a focus on eye movement. The tool had to include linked views, in which users could select Areas of interest on an interactive stimulus, to then be shown an output of user flows. The learning objectives where based on programming, user experience, user interface, backend server understanding, data processing, visualizations and algorithms.

2 INTRODUCTION
Visual communication can be interpreted differently depending on every potential task at hand when people must interpret a visual stimulus. This is not a new phenomenon, however, with the constantly growing amounts of data in the field of spatio-temporal eye movement data [1], there is a clear need for user-friendly tools to interpret the data produced by eye tracking [10, 12]. Interpreting this data is an interesting task and not everyone has the expertise to work with this. For example, when trying to interpret spatio-temporal data, one can struggle to see any sort of pattern since the data has multiple dimensions, we might see that users go over the same fixation coordinates, however, they may be doing this at completely different steps in their general scanning paths. Therefore, more algorithmic and visual support is needed to help researchers identify the trends they need for their data analytics tasks.

In this BEP we describe a web tool (see Figure 1) that allows researchers to visualize their experiment data, that deals with a group of subjects and their scanpaths while answering a given task. From this scanpath data, heatmap is overlaid over the given stimuli, and this allows for researchers to better see the paths that their subjects took. Then the researches can select key junctions like areas of interest (AOIs), and supported by this tool, an analysis of the general scanning trend in terms of the hierarchical flow is possible [8]. Although such general trends aggregate lots of the information it helps to give an overall impression about the scanpath data as a starting point for further exploration task, for example, as a means to build, refine, conform, or reject hypotheses [14]. Hence, the role of such a web-based visual analytics tool is to provide a way for researchers to share their eye movement data and to communicate the findings and insights by starting with an aggregated overview and then digging into details.

The meaning in the visual output cannot only be derived from the scanpath data but also requires context from the task, for example the content of the stimuli and the assigned task for the participant. The content of the stimuli and the tasks will cause each participant to have the freedom to divide the tasks into different subtasks. Finding insights for individual participants can be visualized with standard tools, however, when dealing with multiple participants combined with the spatio-temporal nature, such an analysis can be difficult if only one visualization is supported, hence we focus on multiple coordinated views [22]. For this reason, more data processing, aggregation, algorithmic approaches, and interactive visualizations are combined.

We illustrate the usefulness of our web-based visualization tool by applying it to real-world eye movement data from a formerly conducted eye tracking study investigating the task of solving route finding tasks in public transport maps [17]. Finally, we discuss scalability and limitations of our approach.

3 RELATED WORK
Exploring and analyzing eye movement data [2] by a single visualization like a visual attention map [3, 4] or a gaze plot [11, 24] leads to limitations of the exploration process since data is either aggregated or it suffers from visual clutter [23]. Moreover, if several perspectives on the same dataset are given as in a linked multiple coordinated views approach [22], the data can be inspected from different angles leading to many insights that can be interactively combined by the human observer as it is a typical situation in visual analytics applications [14].

In our approach we go one step further and have designed and implemented a web-based tool that does not come with the challenging problems of how to get installed software packages or to adapt the environment to the requirements of the tool, instead just a URL has to be typed in to the web browser and then the tool can be used right away [6]. Moreover, using such a web tool supports the data analysts to share their eye movement data and to communicate it with the goal to faster find insights by such a collaborative data analysis.

To reduce the learning curve for non-experts in eye tracking we also implemented traditional visualization techniques following the principles of visual attention maps [3, 4] showing an overview about the aggregated fixation data as well as gaze plots [11, 24] giving an overview about the scanpath data on top of the static stimulus, although it can become cluttered [23] for many study participants. As a major contribution and extension to the work of Burch [8] we also show the hierarchical flow of eye movements by aggregating the scanning strategies into common hierarchical trends indicating which AOIs have been inspected in which scanning order, meaning we give a general trend of the scanning strategies which is not supported in most of the tools focusing on scanpath visualization [5, 19].

Such general trends are, for example, difficult to see in visual analytics tools like GazeStripes [16] or the fixation image charts [15] that make use of hierarchical clustering on the one hand, but if too many scanpaths have to be analyzed those approaches do not scale that well anymore and general trends cannot be derived. Also the EyeMSA approach [9] that shifts the scanpath patterns by multiple sequence alignments provide a good overview about the different scanning strategy groups, but they fail to scale to many scanpaths nor do they provide extra perspectives like visual attention maps or gaze plots with which a user is most familiar. The AOI rivers [7] provide an overview about time-varying attention frequencies,
but the hierarchical flow of the eye movements is difficult to see.

Moreover, we integrated several interaction techniques following the categorization by Yi et al. [28] in order to build a useful and easy-to-learn tool for researchers and data analysts working in the field of eye tracking. All of the views are linked while color codings can be adapted to the users' demands [26, 27].

4 EXAMPLE METRO MAP DATASET

![Heatmaps of various metro maps and their eye tracking results](image)

Figure 2: Heatmaps of various metro maps and their eye tracking results

The standardized metro maps that was used initially for this tool was provided by Communicarta Ltd., a well-established company with more than 25 years of experience in creating, designing, and researching public transport information and metro maps. The maps were scaled down to achieve a height of 1200 pixels and the width was on average 1605 pixels (minimum of 871 pixels and maximum of 1894 pixels). They used metro maps from major cities all over the world, since they wanted to perform a real-life study using real maps and have therefore not used artificially created maps. All the maps are independently designed and none of them are the official version used in the public transport of the cities. Even if participants had been to the city and used the transport system, they would most likely not be familiar with the maps used in the study. Forty subjects had been examined (23 males and 17 females) aged between 18 and 39 years (mean of 25.3). All people had normal or corrected-to-normal vision and good color vision. The task given to the users was start at a starting point and use the given metro maps to determine a route from start to end. Whilst this was done the participants where being observed using an eye tracker. The objective of this data collection was to see how to improve the quality of metro maps, with comparison of color compared to greyscale, time taken to complete the task, and now with our tool the ability to see the flows between AOIs. The data that was used to be the example of an experiment that would use the tool we created came from a metro map dataset.

5 EYE MOVEMENT SCANPATHS AND COMPARISON

We designed an interactive visualization focusing on several aspects like supporting several well-known views in a web-based environment. On the one hand, the eye movement data should be shown in an aggregated manner for overview purposes while at the same time allowing to look into details supported by interaction techniques. We achieved the scalability of our approach by aggregating the visual scanning strategies, making it somehow similar to edge bundling approaches [13, 18], but in our case we provide a clearer picture on the strategic scanning behavior by showing an unbundled node-link version of an alternative of a hierarchical graph layout [25].

5.1 Design Criteria

We come up with a list of design criteria when building the web-based and interactive visualization tool for scanpath data.

- **Web based**: The tool should be accessible by the researchers using their web browsers and they should be able to access it without installing any other software (such as R in which the tool is built).
- **Server based**: The tool must handle all the processing on a hosted server. This means that the researchers’ computers do not use any resources and they could run the tool even on devices that cannot handle the computation, allowing even users on less well-performing hardware to use the tool.
- **Overlay of stimuli view and heatmap**: The researcher must be able to view a heatmap overlaid onto the original stimulus that was used in the eye tracking scenario.
- **Hierarchical flow**: From the selected areas of interest, the researcher should be able to see a hierarchical flow in which the scanpaths are aggregated and they could see how the subjects flow through the hierarchy of the selected areas of interest.
- **Linking of views**: When selecting areas on the heatmap, the researcher should be able to change the hierarchical flow diagram by changing the selections on a different panel. The AOIs are selected on one panel and the output of this selection is used as an input on another panel.
● **Selecting areas of interest:** The researchers should be able to manually select areas of interest that can be used in the hierarchical flow visualizations.

● **Clustering:** The tool should be able to manually cluster the fixations of the users into artificial ‘areas of interest’. The researcher should also be able to determine the number of clusters to be used by this algorithmic approach. The approach is the K-nearest neighbor algorithm, using knn in R.

● **Uploading data:** The researchers should be able to upload their own data to the server via the web browser. This is the fixation data from their experiment, and the stimuli that were used. The tool should be able to handle any users uploading their own data, and to process this accordingly.

![Figure 3: An example of a visual attention map with a user-selected color coding](image)

**5.2 Design Implementations**

We will further describe some of the design criteria by focusing on how we implemented them in the visualization tool. For example, we discuss the implementation details, but also the purpose of the visualizations and algorithmic issues.

● **Implementation details:** The programming language used for the tool is R. The main library used was the R Shiny library, this is the main library for creating web-based tools in R. Some HTML is used, and this is mainly via the Bootstrap framework, there is also a Shiny dashboard library that is based on a Bootstrap template using R shiny for the UI of the tool. The main packages used where Ggplot2 and networkD3 for the Sankey diagram (using D3 JavaScript) as well as igraph and VisNetwork for the hierarchical node-link diagrams. The tool was tested for the Edge, Chrome, and Mozilla Firefox browser on Windows.

![Figure 4: An example of the hierarchical flow showing the strategic viewing behavior aggregated over all scanpaths](image)

● **Visual attention map:** A data analyst should be able to get an overview about the aggregated fixation data in form of a visual attention map (see Figure 3 for an example provided by our tool). The visual attention map clearly displays the density and positions of aggregated fixations. The density is visually encoded by a user-selectable color scale which is also provided in a color legend.

● **Hierarchical flow:** The general strategic viewing behavior for a selected list of AOIs can be given as directional flows in a hierarchical node-link diagram while nodes represent the AOIs and the links the transitions from one AOI to another. The thickness of links is used to visually encode the number of eye movements (see Figure 4). The algorithm used is based on the work by Reingold and Tilford [20], which attempts to produce tidy drawings of trees. With the requirements that nodes are placed on a level-by-level basis, a parent node should be central to the children and the children are placed to the left and to the right.
An Interactive Web-Based Visual Analytics Tool for Detecting Strategic Eye Movement Patterns

Figure 5: An example of an interactive Sankey diagram providing another view on the aggregated scanpath data

- **Sankey**: A Sankey diagram [21] was selected due to its versatility in visualizing paths from one node to another and seeing how paths can split and merge. It provides a complementary view to the hierarchical flow visualization while typical interactions are possible like zooming in and out on demand or selecting certain AOIs. Moreover, the linking to the other views can support a better exploration of the strategic viewing behavior, for example, with context to the visual attention map (see Figure 5).

- **Clustering**: We also integrated an algorithmic approach for automating AOI selections, in our case this is built on the K-nearest neighbor algorithm.

Figure 6: An example of first and second AOI selection

Figure 7: An example of the third AOI selection

```
5.3 Design Features
We will give a detailed overview about the design features, how they are integrated in our tool, and what functionality those have.
```

- **Selection of AOIs**: The user needs to be able to manually select AOIs from the visual attention map, using a click and drag method to create their own AOI, then the original rectangular box can be resized and moved by mouse interaction (examples are shown in Figures 6 and 7). Each time a new box is created or a box is moved and stays still for 500ms (this is an adjustable setting) the tool detects the AOI coordinates and starts the layout algorithms. The tool requires the users to manually change the label of the AOI and then select the boxes in the heatmap.

- **Server hosting**: The tool is created in R Shiny, hosted on the Shinyapps.io platform which is the official platform of the original creators or the R Shiny library and the RStudio IDE. However, the tool can also be hosted on a dedicated server, both via cloud computing, such as Amazon web services, and a personal/enterprise server, with no extra software costs. This left us with plenty of options on how to host the tool, and even allowed us to host it on multiple platforms.

Figure 8: The options sidebar
that the tool is usable on screens with different resolutions and scales with the size of the window and display. The tool could even be used on mobile devices, however, due to the nature of touch screens it is not natively supported with the selections and dragging/dropping that the tool requires. Bootstrap tries to ensure that most people using a variety of browsers, operating systems, and even devices can have a good and similar experience, which should future proof the tool for most browser experiences. The tool was based on the shiny dashboard template which is also built upon bootstrap.

- **Movable menu:** The sidebar menu (Figures 8 and 9) is removable, so that once the controls that are placed in the sidebar, are no longer necessary, they can be put aside. They can also be re-opened using the side menu icon.

- **Minimalizable options:** The tool has many options for the user to control. The tool is designed to keep the UI clean and usable, the inputs are put into groups, which are then in turn put into collapsible groups. This allows first time users to not get overwhelmed when they first use the tool and allow users to see all the options of the tool without the need to scroll down.

- **Upload scanpaths and images:** There is an upload button for the fixation data. This only takes one file at a time; each file may contain multiple stimuli and users. Also, the users can upload the images of the stimuli, the user can upload multiple images at once. They can upload an initial image file, and whilst using the tool upload the rest, as it can take some time to upload all of the files to the server (this is mainly dependent on the internet connection to the server, as when the tool is running locally it will upload much faster). The image files must be in a jpeg form and should be named in the same way as the stimuli are labeled in the fixation file.

- **Pre-uploaded data:** The metro maps data set comes pre-uploaded in the tool, this is to allow the users to see how the tool is intended to be used so that they can get familiar with the tool and do a quick check if it is applicable to their research without having to do much effort at all.

- **Select stimuli:** When the data is loaded the users must select which stimuli they will see in the tool. The users can either search within the selection bar (by clicking on the input and then typing, to filter from the selection of stimuli), or scroll to find the desired stimuli, only one stimulus can be selected at a time.

- **Download AOI:** When the users have selected their AOIs, they can download the selection data in the form of a .csv file. This can be useful when they would like to continue their work with the same selected AOIs. The download file will include AOIs selected from all of the stimuli in use.

- **Upload AOI:** This will allow the users to upload their previously downloaded AOI selection data to continue where they left off with their previous session and old AOI selections.

- **Hover over info:** When the users hover over any of the inputs they will be able to see a quick description of what each input does. This is to help as a guide to properly using the tool and remind them of each feature the tool has.

- **Heatmap without image:** Even if the users do not upload their stimuli image, the tool will still process the data, but using the minimum x- and y- coordinates and the maximum x- and y- coordinates as the boundaries of the visual attention map.

- **Naming points by AOI or cluster:** When selecting the Numbering checkbox option, instead of seeing the fixation points, each point in the visual attention map can be represented as a numeric value serving as a label that corresponds to the AOI or cluster that each point is located in (see Figure 10). This allows the user to better link between the stimuli heatmap and the flow visualization

- **Color scheme selection:** The standard colors for the visual attention map range from green to red. However, the users can select several other colors from start to end.
An Interactive Web-Based Visual Analytics Tool for Detecting Strategic Eye Movement Patterns

BE'19, February 2019, Eindhoven, The Netherlands

Figure 11: An example showing two different node-link layouts for the computed strategic viewing behavior

Figure 12: An example of the downloaded AOI data

- Gradient of color on heatmap: The users can also control the alpha (transparency) of the density visualization. This can be helpful when wanting to see the stimuli under the density heatmap.
- Thickness of points: The thickness of the individual fixation point on the scanpath visualization can be adjusted to better suit the users.
- Selecting AOIs: The users select which number the AOI gets, and then using mouse interaction, they span a rectangle to select certain coordinates. These coordinates form an AOI, and then the users can change the number to move on to the next AOI selection. The users can also drag the old rectangle and place it elsewhere and this registered as a new AOI. When the users redo an AOI selection with the same number, this one overwrites the previous one. Also, when a user overlap the same points with another AOI, the highest numerical value will be the one to keep this fixation point in their AOI. This allows the user to create non-rectangular shapes when selecting AOIs.
- Clustering and number of clusters: There is a checkbox to enable clustering, and a slider to determine how many clusters the user wants to select. The K-nearest neighbor clustering algorithm was implemented.
- Minimum number of transitions: There is an option to select the minimum number of transitions from one AOI to the next for it to be registered as a relevant AOI transition. This allows the users to remove more of the random noise from unpredictable eye tracking data, or only focus on the more significant trends.
- Sorting in the flow map: This enables the node-link diagram to automatically perform hierarchical positioning (see Figure 11). The user can still move the position of the nodes manually as algorithms for determining the hierarchy are never perfect. This allow the users to tweak the visualization if needed, to better convey the results. The algorithm is based on the igraph implementation of the tidier drawings algorithms, and plotted using VisNetwork to allow for more customization, such as adding images. The main weakness of the algorithm is that it does not handle too many loops well, therefore we implemented an option to enable and disable using the sorting algorithm, in case the specific scenario has too many loops.
- Select flow visualization: The flow visualization can be changed from a Sankey diagram to a hierarchical node-link diagram (see Figure 11) using the tab views within the boxes in the Dashboard. This allows the users to select which type of flow diagram to display, the tool will only process one at a time to save server resources.
- AOI selection data: Values for xmin, ymin, xmax, ymax, group, and the region are displayed, and are the same values as the AOI selection download (see Figure 12).
- Relatively weighted flow: The user can select to make the data relative per AOI, in this case the data works with relative transitions, where all transitions are based on percentage instead of real numbers. In this the user can see how much percent of the participants transition from one AOI to the other. This was done to help reduce potential visual clutter.
- Weighted directional flow: The arrows connecting the nodes are directed in the same direction of the flow, and there was a weight applied by adjusting the thickness of the arrows to visually display this effect. The weight is applied by the number of fixations subsetted in the AOIs and then the weight is the value of how many paths went from one AOI to the other.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>xmin</td>
<td>ymin</td>
<td>xmax</td>
<td>ymax</td>
<td>group</td>
<td>region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>231.352</td>
<td>375.359</td>
<td>425.2455</td>
<td>795.3254</td>
<td>1</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>453.8814</td>
<td>799.7473</td>
<td>453.8814</td>
<td>799.7473</td>
<td>2</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>453.8814</td>
<td>626.51</td>
<td>621.6655</td>
<td>769.7473</td>
<td>2</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>620.1389</td>
<td>716.0333</td>
<td>791.5212</td>
<td>859.2706</td>
<td>3</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>622.9667</td>
<td>523.6999</td>
<td>794.0999</td>
<td>644.8772</td>
<td>4</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>865.6885</td>
<td>711.3882</td>
<td>1037.626</td>
<td>874.6174</td>
<td>5</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1090.776</td>
<td>618.8366</td>
<td>1387.481</td>
<td>884.8487</td>
<td>6</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>845.2261</td>
<td>129.8042</td>
<td>1259.591</td>
<td>646.9725</td>
<td>7</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>845.2261</td>
<td>368.1714</td>
<td>1264.707</td>
<td>646.9725</td>
<td>7</td>
<td>17_Krakau_51.jpg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 13: Our visualization tool provides several interactive and linked views like a visual attention map with user-selectable AOIs from which the hierarchical flow of eye movements can be computed and laid out as a hierarchical node-link diagram.

- **Roundness of links:** The slider allows the users to change the roundness of the smooth curves of links between the nodes. When placed to 0 the arrows will be straight lines, and when a value closer to 1 is used the arrows will curve more, this allows them to better avoid overlapping with nodes and links.

- **Allow loops in the flow map:** This checkbox allows for loops to be kept or removed within the Sankey diagram. A loop is when an equal number of flows occurs from one AOI to another one and then from the same AOI to the other back again.

- **Minimize boxes:** All the visualizations in the tool are contained in boxes. These boxes can be collapsed, if the users decided that they are not relevant for the current exploration task.

- **Boxes can be moved to change places:** The boxes can also be moved interchangeably with each other to allow the users to customize the UI positioning to their needs.

- **Sankey features:** The Sankey diagram allows the users to hover over the passes and see how many passes where performed from one AOI to another. The individual nodes can be dragged by the users to help better visualize the diagram to the users’ needs, and the image can be saved with a mouse click. The AOIs are represented by the way they are numbered by the user in the selection process.

- **Move nodes:** The user is able to move the nodes in the hierarchical visualization, as there is no perfect algorithm to perfectly place the nodes, this allows the user to help correct the potential small mistakes by the algorithm.

6 **APPLICATION EXAMPLES**

Here is a discussion for the potential applications for the tool. This is just a limited selection of opportunities that we were able to identify and given the nature of the tool where it accepts all data and is not focused solely on a given set of data or research. The applications are both from an academic and industry research perspective.

6.1 **Public Transport Maps**

To illustrate the usefulness of the tool it was applied to the eye movement data that was formerly recorded in a public transport map eye tracking study [17]. The data consists of 40 scanpaths for each public transport map. To show the usefulness, we picked the map of Krakow (see Figure 13), each participant was tasked with finding the optimal route from one point to the other. They were unfamiliar with this specific metro map and are dealing with the visual stimulus for the first time. The only indications of a starting point are visual (green finger and red/white ringed target), this was done to prevent each participant from scanning the metro map for a station name.
First, we used the heatmaps to quickly see what the users scanpaths are focusing on in terms of their fixations using the heatmap visualization. Then areas of interest could be selected and for each one we could determine the popularity of different points on the stimuli. As a next step the sorting of the nodes might be useful.

From this metro map we can see that the users quickly diverge into two parallel paths, this is already clear on the heatmap. However, once we look to the hierarchical node-link diagram, we can see that the divergence happens in the AOI numbered 2. After AOI 2, all paths are rather simple and continue step by step until the destination is reached. Apart from users going from the end to start, this is a common phenomenon with these experiments, as the participants seem to check the beginning when they reach the end.

Now we can look into why people diverge and split from one to another pathway. This can be crucial when a stimulus has a set path that it ideally wants the user to follow. For example, the less optimal path getting chosen more often can be indicative of some bad design points.

From this research we can derive that if improvements where to be made in this specific metro map they should occur around AOI 2. There the participants seem to deviate from each other (see Figure 14).

### 6.2 Future Example - Web Pages

Another example could be if we looked into how participants look at a web page or mobile app. If we assigned the participants to open the app or web page (this would generate a standard starting point), then told them to read the contents of the app or web page until they reach the end and, finally click a set button (an end point), this would help the creators of the app or web page to better understand how their users read their app or web page.

This especially becomes helpful if we want to look into if groups of participants look at parts of the app or web page that link to other parts, as this would be a good way to see how to retain the participants. Also this could be used to see if participants view advertisements, and even some sort of A/B testing to see which advertisements work better. This could help developers of apps or web pages better keep their users engaged, and monetize their work more effectively.

![Figure 14: The AOI where the groups of users split](image)

6.3 Future Example - Movement data

On the same track as this is non-eye tracking data, i.e., any sort of tracking data like, for example, tracking data in a controlled venue like a museum or theme park. This would allow the organizers to see the hierarchical steps the visitors take and then also determine where and why they diverge. Maybe this is not how the original planning of the venue was intended. This would allow for quickly identifying the areas in which the venue would need to make changes in order to optimize their participants experience. As the tool is built around movement data it could be used for all movement data. Perhaps with some slight changes of the tool it could be applied to many different cases of movement data. However, a clear advantage of the tool is our experience with eye tracking and the standardization in eye trackers data output this was the initial priority of the project.

7 DISCUSSION AND LIMITATIONS

The tool has numerous limitations, such as regarding the runtime complexity is an issue given the ability for users to upload their own data. The runtime does not scale linearly and is dependent on the server. For this reason, we recommend users of the tool who want to use it more seriously to run it locally. This way they will not have to share the resources, and due to our lack of resources, the individual CPU core could be more powerful than the shared server CPU. Also, all the data and transformations are stored in the system’s memory, this has never been an issue in testing, however, the largest dataset used was the metro maps dataset, and only a limited amount of users at a time.

There was no budget or server made available for the project. This made hosting the tool on the internet more difficult and time-consuming, whilst also not allowing for the highest possible performance, as the tool is built in R Shiny which works with only a single CPU core.

Furthermore, there is no user evaluation so far, not from the field of eye tracking and not from visual analytics. For example, getting feedback from experts might be a good way to understand the usefulness of the tool and to improve it in the future.

This project was completed within the limitations of a Bachelor End Project, where there was limited access to resources and expertise. Also, the projects success was based on the criteria of a Bachelor End Project in accordance to the Technical University of Eindhoven.

Finally, with the tool being built for all types of data, a large limiting factor was what could and could not be included in the tool. Many ideas that would be valuable to individual research had to be put on the sideline for the sake of keeping the tool and UI usable for the largest possible audience.
8 CONCLUSION

In this Bachelor End Project we presented the hierarchical flow for eye movement data combined with complementary views. Scanpaths are transformed to group them by sets of algorithmically clustered groups based on user-selected areas of interest. These are then plotted as hierarchical nodes connected by directed links. The hierarchical layout algorithm can create a top-down hierarchical node-link diagram to visually display the overall trends and strategic eye movement behavior of a large number of participants. The links have arrows pointing in the direction of the flow of eye movement paths. These arrows are weighted by the number of transitions from one area of interest to another one, the weight is visualized by the width of the arrows and thickness of the lines. The tool can be used in a user-friendly way by visiting a URL, and then the users can upload their own data in the tool-specific data format. This allows researchers to quickly gain insights into their data without requiring any programming or software skills and without installing extra software or adapting their environment. The tool is applied to eye movement data from a formerly conducted eye tracking experiment asking people to find routes in public transport maps. For future work we plan to add more interaction techniques and more insightful ways to analyze the data. However, given that the tool is made for a very general purpose, there is a priority on keeping the user interface as simple and intuitive as possible.

REFERENCES


