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# I Visualize with EyeVisualize

Lars Wolter, Luc Siecker, Onno Kniknie, Robin van Gestel, Tunahan Sari, Wouter Tulp, and Michael Burch

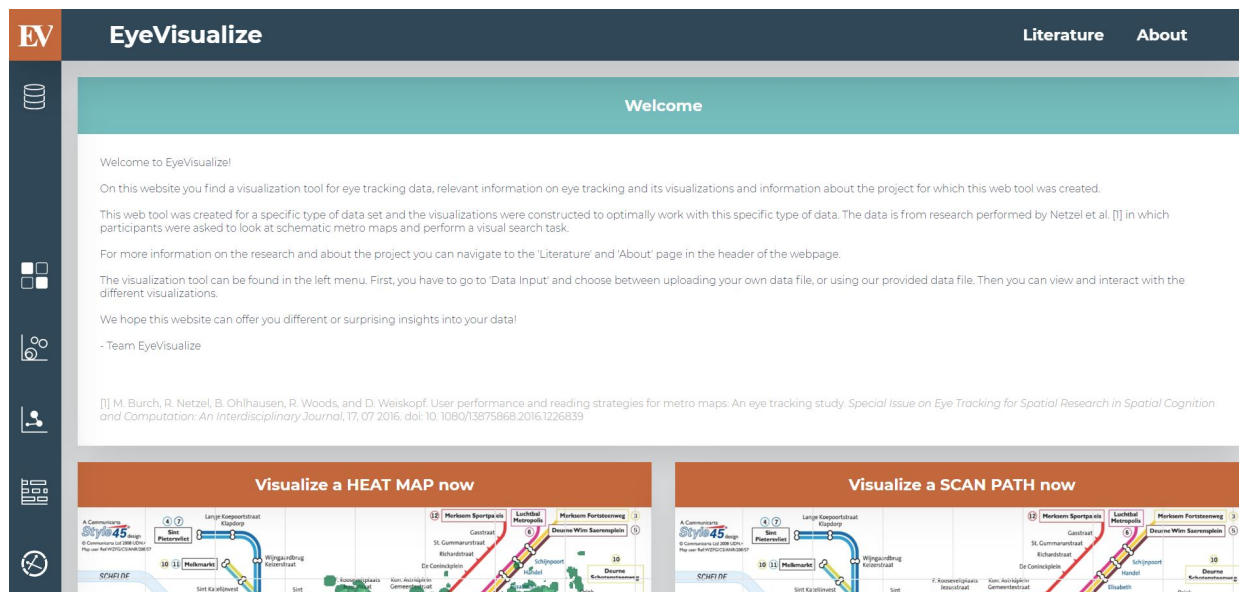


Fig. 1. The home page of the EyeVisualize website including welcome message

**Abstract**—Eye tracking data has become easier to generate in the last years. However, this data type is large in size and highly complex to analyze without any sort of visualization. In order to visualize this type of data, one nearly always has to install software. EyeVisualize was created to offer a fast, web-based application in which data can be uploaded and easily visualized. This application provides users with four different visualization techniques for eye tracking data (formatted in a specific way): a heat map, a scan path plot, a scarf plot, and a circular heat map. Each visualization technique separately has its benefits and drawbacks, however, combined they can offer a full picture of the data, which can lead to novel insights.

**Index Terms**—Visualization, Eye tracking data, Web application

## 1 INTRODUCTION

Most researchers enjoy doing their experiments and research on the topic of their choice. Yet, the majority of this group does not like the steps afterward as much. These steps include analyzing the data and figuring out different ways to inspect the data to find a conclusion. This is not an easy task, because research usually generates a vast body of data. Most research fields obtain results consisting of raw data as lines of code containing a massive amount of numbers. Using only the naked eye, generally, no sense can be made from these results. Thus, visualization is a necessary step in the process of understanding research findings and interpreting this data correctly. Visualization techniques are there to help researchers transform the data into a clear, sensible, and understandable format. This allows researchers to gain new insights into the data. Furthermore, the use of multiple visualizations could even cause the researcher to find aspects in the data set that were not expected beforehand.

One field that suffers from data that is beyond comprehension at

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first glance is the field of eye tracking. The use of eye tracking is a long-standing phenomenon in psychology [24], as it provides objective data for researchers typically investigating subjective experiences or phenomena. Eye tracking data has become less difficult to collect in recent years; in the past, a complicated device in a computer monitor was necessary to collect reliable data. As technology is continuously evolving at a rapid pace, the technology used for tracking eye movement has also advanced into more flexible devices [15, 20]. These new devices make it easier for researchers to utilize eye tracking to gather new insights [19]. Despite the continuously developing technologies, eye tracking data remains complex, vague, and vast in size.

These complex eye tracking data sets provide the researcher with objective measures, which are not easy to interpret. A resulting data file from an eye tracking session consists of hundreds or even thousands of lines of code, as eye movements happen extremely fast; visualization of the data is key to understanding it. Numerous visualization techniques have been produced, each one having a different focus [3]. To visualize eye tracking data in one or more styles, one must nearly always install specific software. This creates a barrier for the researcher to visualize their data, so a web-based platform for visualizing data would be the solution. In this paper, we describe a web-based platform that can transform eye tracking data into four different visualizations. Each visualization provides the user with insights that are impossible to generate from solely inspecting the raw data. Each visualization represents the data differently, which can lead to a variety of possible findings and conclusions. To enhance the usability of the visualizations they have

been created to be interactive, as opposed to static. Those interactions allow the researcher to change some aspects of the visualizations according to the demands of the research or his or her preferences. These interactions are based on the report from Yi et al. [28], who described seven categories of interactions in visualizations, which are organized around the users' intent.

## 2 RELATED WORK

Eye tracking has grown into a field with a lot of applications and uses. Its use is already widespread, although it could be used in more situations than people might realize at the moment. Eye tracking is interesting for web design [13, 16], marketing [27], health monitoring [26] and many more fields [14, 23]. All these fields and studies show the enormous added value of using eye tracking to improve a product, increase effectiveness, or even improve human health. These studies show the reasons for researchers to use eye tracking, they want to know where people are generally looking, where attention is focused the most, and what patterns are visible in peoples gazing behavior.

Since eye tracking is becoming more popular, it is natural that many different methods have been developed over the years that enable an analysis of eye tracking data, each method having its benefits and its drawbacks. Some of the approaches are statistical evaluation [17], string-editing algorithms [21] and visualization-related methods [3]. This report will only explore the visualization analysis for eye tracking data.

As Blascheck et al. [3] stated, "visualization techniques allow researchers to consider other aspects of recorded eye tracking data in an exploratory and qualitative way". Visualization gives the user the tools and possibilities to see the data from a different perspective, which could give rise to new findings in the data.

Visualizations [1, 2, 6–9, 11, 12, 25] are made in a multitude of ways, but they can be categorized into two groups, namely point-based visualization techniques and AOI-based visualization techniques [3].

Point-based visualization techniques focus on the gaze points of the eye tracking participant during the experiment. This includes both spatial information and temporal information of each participant's fixations. Spatial information consists of each location that the participant has fixated on and temporal information denotes the time the eyes are fixated on those locations [3].

AOI-based visualization techniques use the same spatial and temporal information from the data. However, these visualizations add another aspect. All AOI-based visualizations begin with the creation of areas of interest (AOIs). These AOIs are especially important sections of the scene that is being looked at. Determining which areas qualify as AOIs differ between experiments and can be adjusted to fit the research goal. One option is to determine AOIs manually before the experiment; the elements of the scene that the researcher expects to be important areas are qualified as AOIs. The second option is to calculate AOIs after the experiment, based on the viewing behavior of participants; if an area is looked at significantly more than others, it qualifies as an AOI.

Both point-based and AOI-based visualization techniques can be used to answer different research questions and sometimes the use of both is necessary to get a clear view of the data [3].

In addition to the construction of different visualization methods, interaction can also vary in the way they help and support researchers. Yi et al. [28] split the interaction for visualizations into 7 different categories.

- **Select:** *Select* is described as the ability to mark something. Enabling users to mark a subset of data, allows them to visually highlight an interesting subset and therefore follow it more easily. This interaction is especially valuable in highly dense data sets or visualizations containing much visual clutter.
- **Explore:** The interaction *Explore* allows users to view something else than what is currently in view. One example is to show users other subsets of the total data set, such that inspection of parts of the data set can occur in greater detail.

- **Reconfigure:** Yi et al. [28] describe *Reconfigure* as showing users a different arrangement of the data set. Viewing data in another configuration shifts focus from certain features of the data to others. As an example of this category, one can think of sorting columns in a bar chart in various ways.
- **Encode:** *Encode* is defined as to show a different representation. This encompasses changing the visualization as a whole into another visualization. But also color coding of an attribute of the data is seen as an interaction of the category *Encode*.
- **Elaborate:** *Elaborating* the visualization is to show more or less detail. Textual description can be added to provide another representation as opposed to mere visuals only. Or the ability to zoom in or out provides the user with more or less detail.
- **Filter:** The *Filter* interaction works as a literal filter. A condition is applied to the visualization, and based on that condition a particular subset of the data is visualized.
- **Connect:** Yi et al. [28] describe *Connect* as to show related items. A typical example can be thought of in a node-link diagram; when one node is selected, the connected nodes are highlighted, which can reveal hidden relationships between these nodes.

## 3 DATA MODEL AND PREPROCESSING

This section explores eye tracking data in more detail. It opens with general information about eye tracking data, including an elaboration of the data model used. The section ends with an explanation of the preprocessing of the used data.

### 3.1 Eye Tracking Data

This project uses eye tracking data as its source for visualizing and analyzing. This is a specific type of data for the reason that it is based on the movement of the eyes. To understand the basics of eye tracking data, some knowledge will be given about eye movement. This subsection will also give background information about the specific data that is used for creating the visualizations. Lastly, the supported data on the website is discussed.

#### 3.1.1 Eye Movement

The eye's resolution of images varies across the retina; the largest resolution can be found in the fovea and, from this central area, the resolution decreases towards the periphery of the retina.

Ocular muscles enable people to rotate their eyes and in turn, shift their gaze. As the eyeball is rotated, the image formed on the fovea shifts. When people take in a scene, they shift their gaze and thus vary the current aspect of the scene that is seen and attended to.

Eye movement when shifting gaze consists of two elements. The eye alters between saccades and fixations. Saccades are rapid, voluntary, and conjugate eye movements between two fixations. Fixations are the periods between saccades in which the eye remains stationary. By using this pattern of saccades and fixations, humans maintain that their eyes are always directed to the current area of interest [18].

#### 3.1.2 Background on Metro Maps Eye Tracking Data

The web tool was created with the use of a specific data set and the visualizations were constructed to optimally work with this data set. The data is from research performed by Netzel et al. [10] in which participants were asked to look at schematic metro maps and perform a visual search task. This research is a controlled empirical eye tracking study that investigates the different map-reading strategies of participants and assesses their performance. 40 participants got the visual search task to find the route from a start location to a target location while stating the number of transfers that have to be performed during this trip. The metro maps differed in complexity and color scale. Some maps were depicted in gray-scale whereas other maps were in color.

Netzel and colleagues were able to conclude that the design of the metro maps has a significant impact on participant task performance.

Table 1. Excerpt from the metro map CSV data file used for visualizing

Timestamp	StimuliName	FixationIndex	FixationDuration	MappedFixationPointX	MappedFixationPointY	user	description
2586	01_Antwerpen.S1.jpg	9	250	1151	458	p1	color
2836	01_Antwerpen.S1.jpg	10	150	1371	316	p1	color
2986	01_Antwerpen.S1.jpg	11	283	1342	287	p1	color
3269	01_Antwerpen.S1.jpg	12	433	762	303	p1	color
3702	01_Antwerpen.S1.jpg	13	183	624	297	p1	color
3885	01_Antwerpen.S1.jpg	14	333	712	303	p1	color
4218	01_Antwerpen.S1.jpg	15	300	753	293	p1	color
...	...	...	...	...	...	...	...
66382	05b_Frankfurt.S2.jpg	155	200	1212	597	p1	gray
66582	05b_Frankfurt.S2.jpg	156	283	1124	334	p1	gray
67032	05b_Frankfurt.S2.jpg	157	400	945	660	p1	gray
70613	06b_Hamburg.S2.jpg	160	166	391	788	p1	gray
70779	06b_Hamburg.S2.jpg	161	233	264	886	p1	gray
71013	06b_Hamburg.S2.jpg	162	166	1204	1039	p1	gray
71179	06b_Hamburg.S2.jpg	163	350	1295	1037	p1	gray
...	...	...	...	...	...	...	...

The study also identified different reading strategies of the maps. More detail can be found in the report by Netzel et al. [10].

The goal of this report is not to draw any conclusions from the metro map data or to check the conclusions made by Netzel et al. [10]. The purpose of this report is merely to create a visualization application for data in this particular format.

### 3.1.3 Supported Data

EyeVisualize supports comma-separated value (CSV) files that have the following layout. The columns should contain these values: Timestamp, StimuliName, FixationIndex, FixationDuration, MappedFixationPointX, MappedFixationPointY, user, and description (see Table 1 for an example of such a CSV file). Timestamp denotes the time at which a fixation began. StimuliName is the name of the image which was used for the visual search task. FixationIndex is a counter for the number of fixations, which is not used in any step of the processing. FixationDuration specifies the duration of each fixation in milliseconds. MappedFixationPointX and MappedFixationPointY together specify the coordinates at which the fixation occurred. The user specifies which participant was performing the visual search task(s). Lastly, the description denotes the independent variable used in the research; in the case of the metro map data, if a map was presented in full-color or gray-scale.

For the tool to work properly, the system must have access to the correct image stimuli. These images must have the same as the name with which they are denoted in the column ‘StimuliName’. Both the images and the CSV file can be uploaded by the user on the website. Either a ZIP-file containing the CSV file and all corresponding images can be uploaded, or the user can select the CSV file and images and upload them without having them in a ZIP-file.

## 3.2 Preprocessing

Preprocessing the data to a useful form is important for easily constructing the visualizations in later stages of the process. The preprocessing commences with parsing the CSV file. Using a Python script, the CSV file is read in and transformed into a 2D list. Then this list is processed into two different dictionaries for two different purposes. The first dictionary simply has all different stimuli as its keys, and stores all gaze points under the stimulus they are on. The second dictionary has all stimuli as keys, like the first dictionary, but each stimulus stores another dictionary, making it a 2D dictionary. Each dictionary has every

participant as its key under each stimulus. Then all the gaze points of a participant on a stimulus are stored under their respective keys in the 2D dictionary. This way, each gaze path is already separately stored. If the gaze path is used later, for the scan path visualization for example, simply the corresponding stimulus-participant key has to be used. As an example, `dictFirst["New_York"]` returns a list of all the gaze points on the stimulus named New York. And `dictSecond["New_York"]`[p14] returns a list of all the gaze points participant 14 made in New York.

## 4 VISUALIZATION TOOL

In this section, the visualization tool is explained. First, the server that the website is built on is discussed. Then it explains the design and implementation of the graphical user interface (GUI). The following subsection gives an elaboration of the separate visualizations and their supported interactions. Finally, the section will end with an explanation of the benefits of EyeVisualize.

### 4.1 Server Side

The website is built on a Django framework and runs on an Apache server provided by the Eindhoven University of Technology; because of this, the website is only available when you are connected to the VPN. It runs in a development mode on a specific port, due to the limitations in aliasing addresses of multiple Django applications on the same server.

### 4.2 Graphical User Interface (GUI)

The visualizations were designed by using the Bokeh library in combination with Python. Furthermore, the website was created with HTML, CSS, and Javascript.

The website contains a side menu through which the visualizations easily be accessed (see Fig. 2). The first step is to navigate to the *Data Input* page. There the user has the option to upload data or use the provided data (see Fig. 3). The provided data is comprised of a CSV file and the corresponding images of the various metro maps (see Table 1 for an excerpt of the CSV file) from the research by Netzel et al. [10]. If the user chooses to upload their data, a CSV file and all corresponding images must be uploaded, either separately or in a ZIP-file. The program will then process and visualize this data.

After choosing the preferred data, the user is shown the four different visualizations, which are linked with each other (see Fig. 4). To view a particular visualization in more detail, the user can click in the side menu on that visualization which leads to a page on which only that particular visualization is displayed.

The website also contains a literature- and about page. The literature page consists of background information on each visualization and the about page gives an overview of all project members. The about page also contains a video created by the team explaining the project, the website, and the visualizations. Those pages can be accessed by the links in the top header.

### 4.3 Visualizations

Trying to understand data by using a single type of visualization can result in misleading ideas and findings. To avoid such problems, it is generally recommended to make use of different types of visualizations. In this section, each implemented visualization technique is explained.

Four visualization types are implemented on the website: a heat map [5], a scan path plot [29], a scarf plot [22] and a circular heat map [4]. The designs are described as well as their benefits and potential disadvantages. All visualizations have a page specific to them on the website but there is also a page containing all four visualizations next to each other. This page has all visualizations and its interactions linked with each other; this overview page is visible in Fig. 4.

#### 4.3.1 Heat Map

The first two visualizations are point-based techniques. The focus of these visualizations is thus on the separate coordinates that a participant views during the experiment.

Heat maps visualize eye gazes by aggregating all data for all users on one stimulus and consequently use a color scale to indicate relative

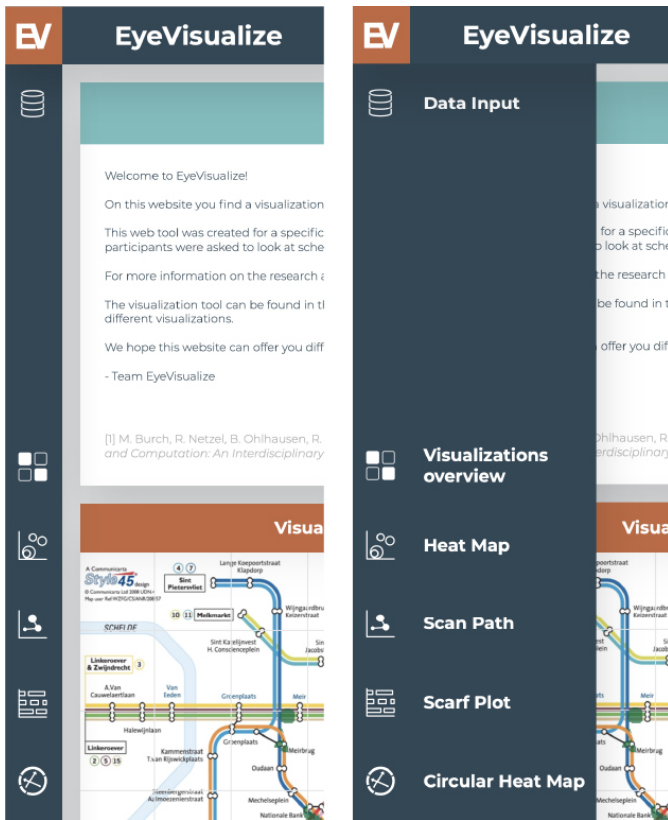


Fig. 2. The side menu present on the website that is used for navigating between all different pages including the pages with the visualizations

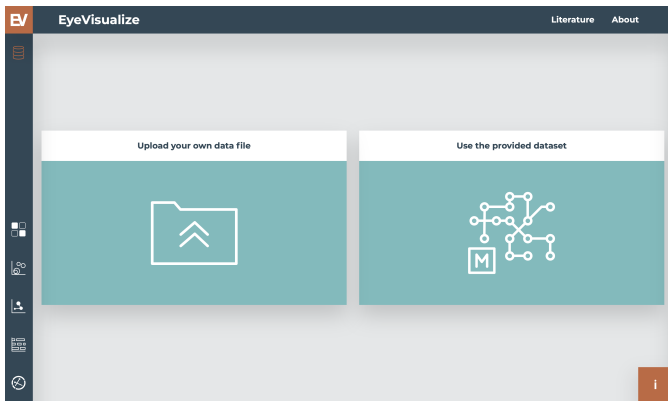


Fig. 3. The data input page with the options between using the metro map or using an other data set that can be uploaded by the user

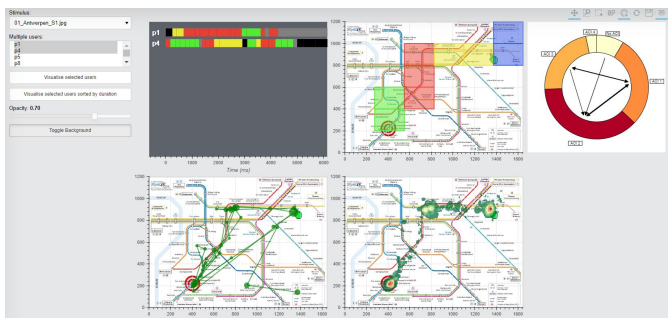


Fig. 4. The overview page on the website containing all four visualization with linked interactions visualizing participants p1 and p4 on the scarf plot and scan path plot, visible on the website

viewing behavior. Both spatial and temporal information is taken into account when computing the relative viewing behavior. The number of fixations on a specific location and the duration of the fixation contributes to the total attention for a certain area. This type of heat map is called an absolute gaze duration heat map [5]. The main aim of this visualization technique is to enable easy identification of areas that are attended to more often than others. The areas that receive more viewing attention can be a basis for determining AOIs.

Fig. 5 shows a heat map visualization with the metro map data on the website. The color coding is a color palette from green to red, with red being the most viewed areas and green the lesser viewed areas.

#### 4.3.2 Scan Path Plot

The second point-based visualization is the scan path plot.

A scan path is a path that a viewer travels with his/her eyes on the image. These paths consist of two elements: saccades and fixations. Using this type of visualization one can easily find focus points if data is minimal. A potential downfall of scan path plots is namely visual clutter. When displaying long scan paths in duration or multiple different scan paths simultaneously, there is a high probability that there is overlap, and thus a chaotic result. The main aim of a scan path visualization is to find patterns in the data and give a possibility to gain insight on efficiency in the gaze path. [29].

Fig. 6 shows a scan path visualization with the metro map data on the website. Fixations are visualized by circles, with sizes that correspond to fixation duration. Lines connecting circles represent saccades between two fixations.

#### 4.3.3 Scarf Plot

The two previous visualizations were point-based. The following two visualizations are created using AOI-based techniques. For both of these visualizations, the AOIs are calculated based on the data from the experiment. Thus, the AOIs result from the data and were not manually chosen beforehand, this will be explained in detail in section 5.1.

A scarf plot consists of two figures essentially. First, the stimulus is displayed with the AOIs indicated by color. Second, the actual scarf plot displays time on the x-axis against participants on the y-axis. On that timeline, different colors denote which AOI is attended to at that moment by that participant and the size of these colored boxes shows the duration that the participant focused on this AOI.

Having multiple timelines of different participants lined up underneath each other can offer insights. General patterns of attending to specific AOIs can be seen, and deviations from those patterns can be located easily. The scarf plot is also useful in comparing different independent variables with each other while looking at multiple participants at the same time.

Fig. 7 shows a scarf plot visualization with the metro map data on the website. The AOIs are indicated by different colors in the left figure and correspond to the instances in the right plot. Black sections in the timeline indicate time spent looking at an area of the stimulus that is not in any AOI. Grey sections indicate time segments in which the participant has no gaze points recorded.

#### 4.3.4 Circular Heat Map

The last visualization is also an AOI-based technique. Again the AOIs are computed based on the data after data collection.

Similar to the previous visualization a circular heat map also consists of two figures. Fig. 8 shows a circular heat map visualization with the metro map data on the website. First, a visualization of the AOIs on the stimulus is displayed. Second, the actual circular heat map is visualized. This consists of a circular plot with each section of the circle corresponding to an AOI. The width of each wedge is determined by the total time spent attending to that AOI. The color is based on the number of gaze points in the AOI on a spectrum from yellow to red; the more red the wedge, the more gaze points the AOI contains. The center of the circle is filled with arrows. Each arrow indicated a shift of gaze from the AOI at the base of the arrow to the AOI at the tip. When there are five or more AOIs, the number of arrows can be very cluttering. Therefore, only the most noteworthy arrows, with a number

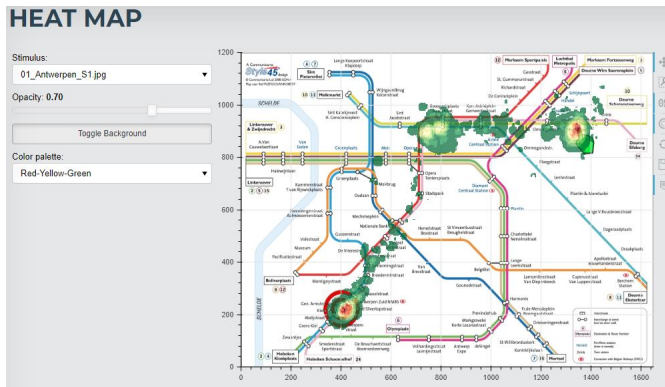


Fig. 5. The heat map visualization with the added option to change the color palette, using the metro map data, visible on the website

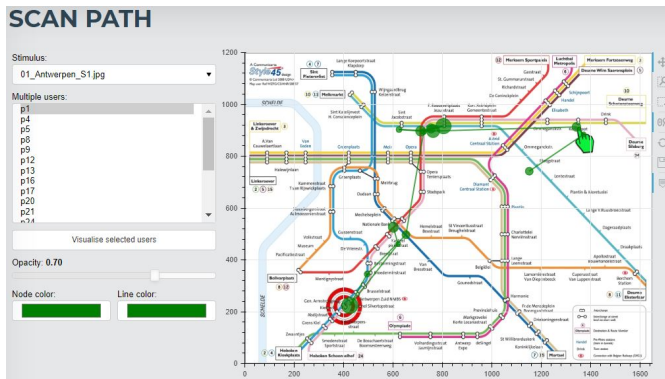


Fig. 6. The scan path visualization with the added option to change the colors of the nodes and lines, using the metro map data, visible on the website

of transitions larger than a certain threshold, are shown. The width of each arrow is determined by the number of transitions.

A more advanced name for this visualization is an AOI transition and completion time diagram. This visualization gives a clear view of the percentage of the time that is spent looking at all the different AOIs [4]. This can be useful for researchers to find the most focused on AOI and compare this to the viewing percentages of different AOIs.

#### 4.4 Interaction Techniques

The web-based visualization tool contains several interactions based on the interaction categories as described by Yi et al. [28]. The interactions that are included are visible in Fig. 9. Not all visualizations have access to the same interactions so the interaction activation buttons differ for every visualization.

Interaction techniques implemented for each visualization:

- **Pan:** This interaction gives the user the ability to move the visualization around to get different parts of the visualization in the middle of the screen. Panning gives users the freedom to focus on certain parts that they are interested in. Panning falls under the interaction category *Explore*.
- **Selection zoom:** This interaction allows the user to zoom into a specific area that is chosen by selecting a rectangle (box) with the cursor. Similar to panning, zooming also allows users to focus on specific parts of the visualization. The Selection zoom is part of the interaction category *Elaborate*.
- **Wheel zoom:** This interaction gives the user the ability to zoom in and out on the visualization at the point of the cursor by use

of the mouse wheel. Similar to the selection zoom, wheel zoom shares the interaction category of *Elaborate*.

- **Reset:** Reset returns the visualization to its original state. If the user has previously interacted with the visualization by for instance zooming in, using the reset function, the figure is zoomed out to its original state. This interaction does not fall within one of the categories that are named by Yi et al [28].
- **Save:** Saving offers users the opportunity to download the visualization as currently displayed in the browser as a PNG file on the user's computer. The interaction of saving the visualization does not directly fall within one of the categories as specified by Yi et al. [28].
- **Tool-tip:** This interaction provides the user with a textual description of data points. If this interaction is used and the cursor is hovering over a data point, a label appears and displays properties of the data point (for instance the spatial location). The use of this tool is visible in Fig. 10 and Fig. 11. This interaction is great for users to gather more information on certain points in all visualizations. This interaction is an example of the interaction category *Elaborate*.
- **Opacity slider:** This slider allows the user to change the opacity of the data visualization that is displayed on top of the stimulus image more or less see-through. Having this function helps to view the picture underneath the plot clearly if necessary. This interaction is part of the category *Encode*.
- **Stimulus selection tool:** The user can choose which stimulus or stimuli are visualized. This gives researchers the ability to explore their data set the way they want it. This interaction falls in the category *Filter*.

Visualization specific interactions:

- **Participant selection tool:** The scan path and the scarf plot visualize the data from one or multiple specifically chose participants, so this means that the user can choose which participants will be visualized. This allows the researcher to find differences or similarities in participants. This interaction falls in the category *Filter*.
- **Data point selection:** Similar to the selection zoom interaction, the user has to select a box with the cursor. For this interaction, the data points within the box are selected and shown. Data points outside of the box are not visualized anymore. This interaction is only possible with the scan path plot. As the user can select stimuli, the overarching interaction category is *Select*.
- **Heat selection tool:** The heat map has an interaction specific to this visualization called the heat selection tool. Using this tool a user can click on a specific color of heat and only this color of heat will be visible on the heat map. This tool is useful for researchers that want a figure showing only one specific heat for more detailed and clear information. The heat selection tool falls in the categories *Filter* and *Connect*.
- **AOI selection tool:** The function of the AOI selection tool is that if a user has its mouse on an AOI either in the AOI map, the scarf plot, or circular heatmap, then other AOIs will decrease in opacity leaving that one AOI clear in the view. The working of this tool is visible in Fig. 10. This can be used to find what AOI is located where in the scarf plot and circular heat map and this makes looking at those visualizations easier. This tool falls in the category *Explore*.
- **Gaze point connection tool:** The gaze point connection tool is a tool only usable on the scan path visualization and is activated by hovering over gaze points. The gaze points will then change color to red together with the lines and gaze points directly connected

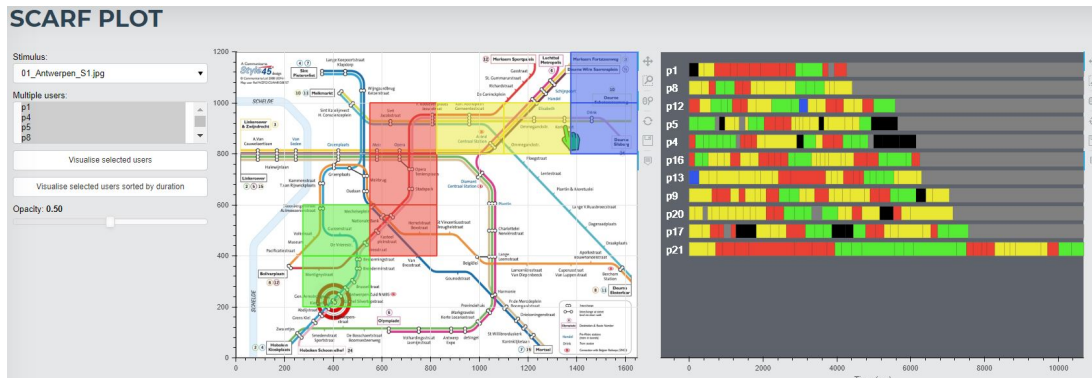


Fig. 7. The scarf plot visualization sorted by duration using the metro map data, visible on the website

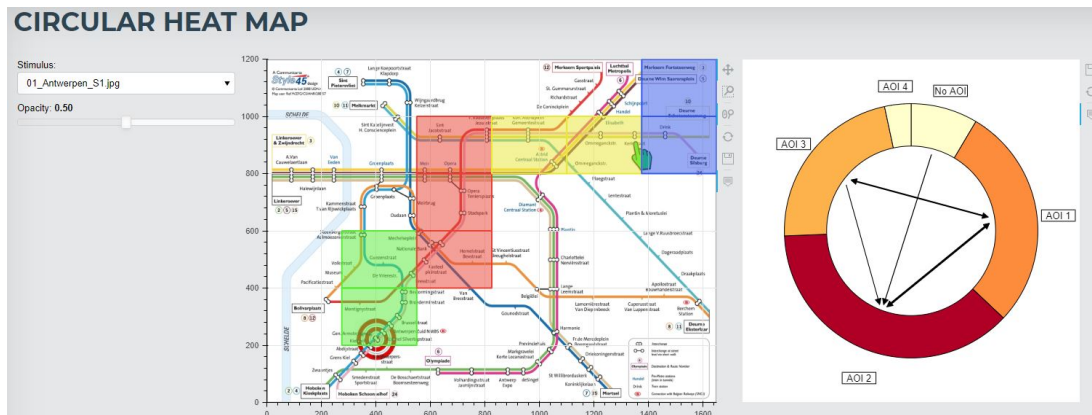


Fig. 8. The circular heat map visualization using the metro map data, visible on the website

to the gaze point where the mouse is currently on. The tool also gives a number to every gaze point starting from one with the first measured gaze point and counting upwards with later gaze points. These numbers are displayed when hovering over the gaze points in the scan path visualization. An example of this tool in use is visible in Fig. 11. The use of this tool is to clarify the chaos in the scan path visualization and make it easier to gather interesting results out of this visualization. This tool shows connected gaze points and therefore falls into the category *Connect*.

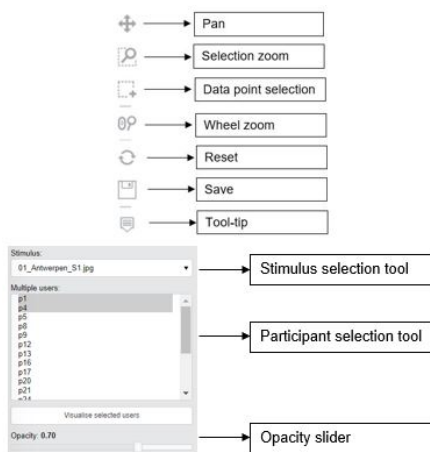


Fig. 9. The interaction selection tool that is present next to every visualization to control the interactions

- Color selection:** The heat map and the scan path both have the option to change the colors of the visualized elements. The heat map gives the user the opportunity to change the color palette of the heat that is visualized. The scan path has two separate options, the color of the nodes, representing gaze points, and the color of the lines can be changed separately. These color-changing options can be adjusted on the left-hand side of the visualization as the bottom option in both visualizations, this is visible in Fig. 6 and Fig. 5. These interactions will make sure that the visualized elements will be visible in stimulus images with different color usages. This interaction is part of the category *Encode*.
- Sort users by duration:** The scarf plot has the option to show visualized users sorted by name or by the total duration of their gaze path on the stimulus. After selecting the desired participants this distinction can be made by clicking one of the two buttons. This gives the researcher an extra way of gaining insights from their data. This interaction reconfigures what the user sees on the scarf plot and is therefore part of the category *Reconfigure*.

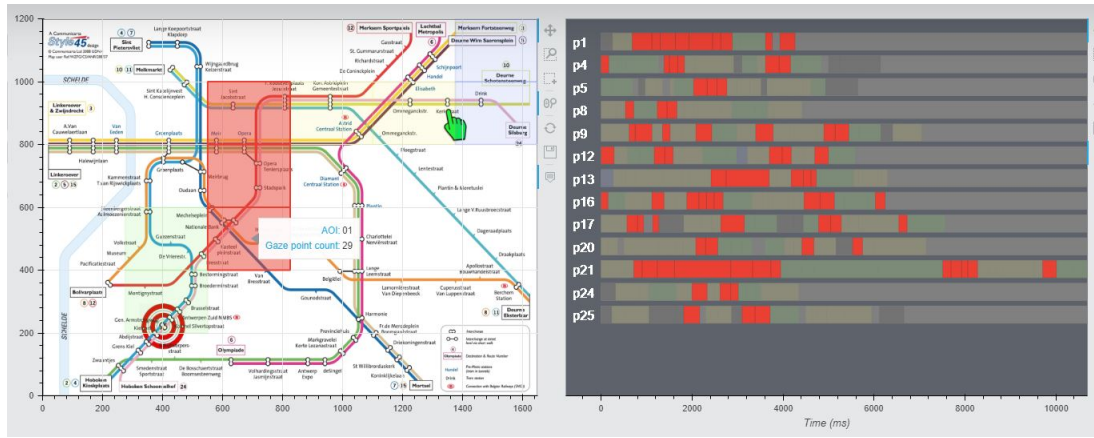


Fig. 10. The scarf plot visualization showing tool-tip information on AOI 01 and highlighting AOI 1 using the AOI selection tool

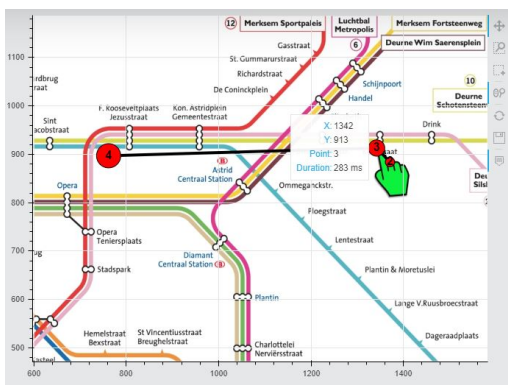


Fig. 11. The scan path visualization showing tool-tip information and working with the gaze point connection tool on gaze point 3, connecting gaze point 2 and 4 with it

#### 4.5 Benefits of EyeVisualize

EyeVisualize consists of the four visualizations and the added interactions that are named previously in this section. All these visualizations can be looked at by themselves to answer specific research questions. The heat map is perfect for looking at where exactly attention is focused most. The scan path visualization will show patterns. Circular heat map information is great to get an idea of which areas are the most important. And lastly, the scarf plot can be used to find compare participants' focus on AOIs.

Each visualization on its own has its qualities that are useful for certain research questions, but the power of this tool is that it contains all the aforementioned visualizations in one location. This makes it easy for the researchers to use multiple visualizations at the same time and all these visualizations can be adjusted to the will of the researcher. The heat map and the scan path plot can be used together. To get a general idea of all participants one can inspect the heat map. This general information can be used to make more sense of the patterns in the scan path visualization. The same goes for the scarf plot and the circular heat map. The scarf plot is a great addition to the circular heat map, while the circular heat map is more general, and interesting participants can be viewed in more detail using the scarf plot.

### 5 TECHNICAL INFORMATION

This part of the report elaborates on how the team created the tool. This includes the technical strategies used for creating the visualizations and other elements of the tool.

#### 5.1 AOI Calculation

The AOI calculations are made based on the number of gaze points and their coordinates on a 2D plane. To determine areas that researchers are most interested in, the given stimulus is divided into smaller sections. Each section comes out as a rectangle based on the selected image's properties. When each section's top-right edge is considered, counting the number of gaze points on a specific section becomes achievable and the same procedure can be done for each gaze point recursively. If a gaze point's x-coordinate is greater than section [0]'s top-right edge's x-coordinate, then section [1] is considered. Until the condition is not satisfied, the value is increased by 1 and when the condition is not satisfied, the same procedure applies for gaze points y-coordinate value. When all the gaze points, and the section they are inside of, are calculated as described and named as each tile's "score", the only task left to handle is logically combining these sections.

However, the amount of AOIs is not known, and combining two side sections is quite easy since they are next to each other when they are printed in a list. To solve these problems, the greatest score is saved in memory and initially, the section with the highest score is considered. If the section's score placed on the starting section's left has a greater score than the score in memory divided by 7, then the pointer moves left. When it gets impossible to move left anymore, the same procedure applies for the section down below the pointer. At the end of the procedure, the remaining section is considered as the starting point of the AOI. The determination of AOI follows a similar structure, the pointer goes right then up, if it is possible, and keep all the indices of sections that are passed over, in a list. When it is not possible anymore for the pointer to move, set the score of all sections to 0 and recursively repeat the process if there is a section's score that is greater than the score in the memory divided by 7. If it is possible, then there will be multiple amounts of AOIs and usually, this is the case since gaze points are not collected in a considerably small area. As an output, a list is created and printed like  $[[0, 1, 4, 5], [12, 13], [6, 7, 10, 11, 14, 15]]$  where it states all 3 different AOIs and their sections. This information is provided to the scarf plot and the circular heat map since they are AOI-based calculations.

#### 5.2 Heat Map

To derive the colors on the heat map, the "heat" on the stimulus is taken into account. The heat of a certain point on the stimulus is a numeric value, representing the attention paid to this point. These heat values are stored in a grid. For performance enhancements, the width and height of the grid are both scaled down by 3. This means that each "coordinate" in this grid represents a box of 3 by 3 pixels on the stimulus; a 3 by 3 box was selected because it is the best trade-off between performance and visually noticing that the resolution is lower. For each fixation, the area of a circle, with the fixation duration as its radius, is updated in the grid by adding 1. Because the durations are



denoted in milliseconds, the radii of the circles can become very large. Therefore the fixation duration is scaled down by a constant factor to maintain performance and to keep the heat map readable. The values of this heat are then mapped to a green-to-red color spectrum. Lower heat means a green color, higher heat means a red color. The contents of the grid, in combination with the color spectrum, are drawn on top of the stimulus.

### 5.3 Scan Path Plot

Scan Path plot is one of two point-based visualizations where AOIs are not calculated. Unlike AOI calculations, you see all the gaze points even if they are not related to actual interest, and no gaze-point is inactivated. When the data is sorted by timestamp, visualizing all the gaze points and their links are going to represent a realistic graph. In order to visualize, first, all the gaze points' coordinates are collected in lists with their duration times. Then each gaze points' location gets adjusted while their size is also getting adjusted based on their duration time. When all these are set, two gaze points' location is collected and the distance is measured recursively to visualize the links in between them. After receiving all the necessary information, with the help of Bokeh the intended graph comes out and necessary information which is collected during the calculation process is transmitted to the front-end for provided tools to actively work. However, if the data is not sorted as described, then creating links will cause an illogical representation and the only way to fix this problem is fixing gaze points and their links later on.

### 5.4 Scarf Plot

With the AOIs calculated as described in section 5.1, some extra calculations have to be executed before the scarf plot can be drawn. For every user on the given stimulus, if they have a gaze path on it, the start time and duration of each gaze point, as well as the AOI the point is stored in a dictionary with the users as keys. If the experiment from which the data was gathered did not reset the timestamp for every user this needs to be compensated. In this case, subtract the timestamp from the first point in the gaze path from every other point in the path. This step is not crucial, because these values can still be gotten from the original dictionary, but it makes drawing the scarf plot considerably easier.

To draw the scarf plot using Bokeh, the 'scarf' of each user is drawn on a light grey stripe. This strip serves as a background for the individual scarfs. Seeing that background signifies that there is no measured fixation of the user at that time. Now, a rectangle is drawn for each gaze point in the path. The width of this rectangle is equal to the fixation duration of the gaze point. And the middle x-coordinate of where the rectangle is drawn is then equal to the timestamp of the point, plus half the duration. The color of each rectangle should represent the color of the AOI, in the picture, the point is in. To represent points that are outside an AOI, the rectangle is colored black.

Using the dictionary created for the scarf plot previously, one can also easily add a hover tooltip for the rectangles, displaying the time at which the point starts, the fixation duration, and the number of the AOI it is in.

### 5.5 Circular Heat Map

Like the scarf plot, the circular heat map is also based on the AOIs calculated as described in section 5.1. To retrieve the 'heat' of an AOI, simply adding up the gaze points in all the tiles and then summing up the totals of the tiles within each AOI. While going over these points, it is also possible to add their fixation duration to get the total gaze duration per tile and thus per AOI as well. The transitions to and from AOIs are stored in a 2D list with height and width equal to the number of AOIs plus 1 because there is also information stored for the tiles outside of AOIs. To detect a transition, it is possible to go over the gaze paths of all users and look at all points. If the previous point is within a different AOI than the current one, then there is a transition. This is then logged in the 2D list by adding 1 to the following index combination: `transitions[previousPointAOI][currentPointAOI]`. To

highlight the noteworthy transitions, transitions that occurred more than a certain threshold are stored. This threshold is decided by

$$\frac{\text{total amount of AOI transitions}}{\text{number of AOIs} * \text{constant}}$$

The current software uses 3.5 as a constant.

Now the circular heat map can be drawn, mainly using the native wedge and arrow functionalities in Bokeh. The 'width' of each wedge is simply calculated by

$$\frac{2\pi * \text{gaze duration AOI}}{\text{total gaze duration stimulus}}$$

The color of each wedge is derived from the heat of the AOI it represents. Like on the heat map, the color is decided by a color palette in Bokeh. By now, what is drawn shows a pie chart of the AOIs, but to show the arrows in the middle a white circle is drawn over the center. To draw the arrows, the 'attachment point' of each wedge is first calculated. These attachment points lay on the perimeter of the white circle, and in the middle of the angle of the wedge. The noteworthy arrows are then simply drawn from one attachment point to the other corresponding attachment point.

## 6 DISCUSSION AND LIMITATIONS

EyeVisualize is of great use for researchers that make use of eye tracking. These researchers can improve their results and increase the clarity of their results towards everyone, from professionals to novices in the field of eye tracking. Using EyeVisualize would give the research a bigger reach into the public to spread their findings and the message that may be connected to these findings. Another positive point about using the tool is that the visualizations are simple to read, which makes it easier for the readers to remember the visualizations and the research it was based on.

The team had a great focus on the creation of a fast program, so all visualizations were programmed with running time in mind. Throughout development, the team has gone back to previously finished scripts and made performance improvements. This type of optimization made sure that the final product does not waste the time of users and presents visualizations as soon as possible.

Furthermore, this report shows the general ideas used for making the visualizations present in this tool. This information can be used by other people to recreate and improve upon this tool. Such a recreation can focus on other visualization types, interactions, and data formats, which can be of use to other or more people as a result.

This research is limited by the fact that the data that is used by the program has to be in a specific format for the tool to work. This format is visible in Table 1 and explained in section 3.1.3; other formats do not work with this tool. This could be the reason for a lot of researchers that they cannot use this tool in their research. For future work, the tool could be improved by making the tool work with more data formats that are frequently used. Only this was not plausible in the time frame that was given for this project.

Another limitation of this project was the fact that all the group and feedback meetings had to be in an online format due to COVID-19 lockdown measurements. With the knowledge that is available now, this did not matter much for the team, as online meetings did not hinder progress. However, meetings in person might have given better results. There is no way of knowing for sure if the project would have been different if COVID-19 was not a factor.

The final limitation worth noting is that this tool is only accessible via the use of the TU/e VPN that can be used by TU/e students and people that work on the TU/e. This dramatically decreases the number of people that this tool could reach. The TU/e is a technical university that also conducts eye tracking research. For instance, Michael Burch is an assistant professor on the TU/e and he is co-author of some articles used as information for this project [3, 10]. Thus, our tool could be of great use for TU/e employees and students, but not for people who do not have access to the TU/e VPN.

## 7 CONCLUSION

This research project has created a tool that can be used by researchers, who make use of eye tracking data, to increase the quality of their research by giving the opportunity to create four different visualizations of the data gathered in their research. These visualizations can be changed and altered using interactions that are added into the visualizations. All four visualizations answer different types of questions and when looking at all four of them together, even more information can be gathered from the data.

The created tool could be recreated using the technical handles giving in this report, which could make for interesting other uses of the visualizations implemented in the tool. For future researchers, there are a few improvements that would have the most positive impact on the tool. The tool should be placed on a server that is accessible outside of the TU/e, to allow more people to use the tool. It is also recommended to make the tool able to use more data formats instead of the one format that this tool can use.

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