A Visualization Tool for Eye Tracking Data Analysis in the Web

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ABSTRACT

Usability analysis plays a significant role in optimizing Web interaction by understanding the behavior of end users. To support such analysis, we present a tool to visualize gaze and mouse data of Web site interactions. The proposed tool provides not only the traditional visualizations with fixations, scanpath, and heatmap, but allows for more detailed analysis with data clustering, demographic correlation, and advanced visualization like attention flow and 3D-scanpath. To demonstrate the usefulness of the proposed tool, we conducted a remote qualitative study with six analysts, using a dataset of 20 users browsing eleven real-world Web sites.

CCS CONCEPTS

• **Human-centered computing → Visualization systems and tools**.

KEYWORDS

Web interaction, gaze visualization, scanpath, heatmap

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1 INTRODUCTION

Eye tracking is used for analyzing attention in several domains, such as medical, sports, commerce, and human-computer interaction studies [Blascheck et al. 2016; Duchowski 2002; Holmqvist et al. 2011; Nielsen and Pernice 2009; Poole and Ball 2006]. Gaze data from eye trackers, i. e., attention of users on screen contents, provides feedback on the implicit behavior of users, which is arguably more natural and intuitive to interpret than the conventional indicators such as self-reported feedback or plain clickstream analysis [Schiessl et al. 2003]. As eye-tracking hardware is becoming cheaper and widely available, the relevance of gaze data and its role in human-computer interaction studies is increasing significantly. One of the most common interfaces for human-computer interaction are Web pages. Users interact with Web pages through a Web browser that presents the contents of a Web page through a viewport. In this setting, gaze-based usability analysis could help us to understand how users interact with a Web page so that we can address shortcomings and design issues. Recent works even describe crowd sourcing of eye tracking on Web sites [Eraslan et al. 2018], i. e., collecting data from a large number of users. For usability studies on the Web, usually one image per Web page is composed, which offers a common space for interaction data of all users who have visited that Web page. The images can be enriched with collected interaction data, i. e., gaze and mouse data, such that analysts may correlate the contents of the Web page with the interaction behavior of users. Analyzing the sheer amount of gaze data on Web page representative images for several users is a challenging task, and there is a need for effective visualization tools to support efficient analysis.

We developed a Web-based tool for the visualization of gaze data. It allows for data import, offers various visualizations, includes filtering and correlation of user data, and enables automatic clustering of gaze data to tackle the challenge of cluttered visualizations with the increasing amount of data. Our dataset and the tool can be accessed online at https://eyevis.west.uni-koblenz.de and is open to use unlike the existing commercial platforms. We have evaluated the tool and visualizations with six analysts from the fields of information systems, psychology, science, and usability analysis.

2 RELATED WORK

There are various commercial tools that allow visualization of gaze data on an image of the stimulus. For example, eye-tracking devices are sold in combination with desktop-based software like Tobii Studio [Tobii AB 2016] and SMI beGaze [SensoMotoric Instruments 2020]. Recently, Web-based products have emerged, offering eye-tracking usability studies of Web sites either with dedicated hardware [CoolTool 2020; EYEVIDO GmbH 2020] or a Web cam [Eyezag GbR 2018; RealEye sp. z o. o. 2020; Tobii AB 2020]. However, there are not many publicly available tools to provide effective visualization of gaze data or to enrich the features of the commercial products. Burch and Kumar [Burch et al. 2019a] proposed a Web-based visual analytic tool where users can upload, share, and explore data with others. However, the tool is designed to detect strategic eye movement patterns when the areas of interest (AOIs) are predefined on a static stimulus. For Web usability studies, the AOIs need not

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to be predefined, and it is important to show gaze data overlaid on the composed images of the pages of a Web site. The challenge in visualizing gaze data in relation to the Web page stimulus is its spatial and temporal property, which must be mapped to the two-dimensional space of a Web page. Existing tools for visualization mostly implement scanpath and heatmap visualizations to map gaze data onto the image of a Web page [Eraslan et al. 2019].

A scanpath [Goldberg and Kotval 1999; Holmqvist et al. 2011] represents each fixation as a circle. The transition between two fixations is plotted as a connecting line, which signifies a saccade. Scanpath visualizations maintain the temporal property of gaze data. However, it does not aggregate the gaze data of multiple users. The scanpath visualization even tends to be cluttered, if scanpaths of multiple users are overlaid.

A heatmap [Bojko 2009] shows the distribution of gaze data across the stimulus. It aggregates the fixations of multiple users and shows hotspots, aka heat, of attention. The level of attention is color coded. There is no recognized standard of constructing a heatmap, but rather specific types of heatmaps are designed for specific purposes. Heatmaps allow for a fast impression about the overall attention on a Web page. However, any temporal information of attention is lost. In a heatmap visualization there is no difference whether a user first looked at the product picture and then on the buy-button or vice versa.

Researchers have proposed more elaborate visualizations that we take as inspiration [Blascheck et al. 2017; Burch et al. 2019a,b]. However, in these approaches, usability analysts must define an AOI on a Web page. The tools can compute the attention and interaction with each AOI. Besides displaying statistics, one can display the transitions in attention from one AOI to another AOI across the users with arrows [Holmqvist et al. 2003].

3 VISUALIZATIONS

Instead of relying solely on the traditional scanpath and heatmap visualizations, we propose to combine them for more interactive analysis, and introduce new approaches, like attention flow with an automatic AOI computation, and a 3D-scanpath that maps the temporal information onto the depth axis.

Combination of heatmap and scanpath. A heatmap provides a good overview about general attention on the entire Web page. A scanpath preserves the temporal property of the attention and is well suited to understand individual interactions, especially before clicking a link or button. In our tool, we combine both visualizations to provide an overview and simultaneously drill down to individual interaction behaviour. Initially, we visualize a heatmap that shows the overall attention of users on the Web page. In addition, we display indicators of mouse clicks on top of the heatmap (the color of the indicator represents individual users). A click on an indicator hides the heatmap and displays the scanpath before the mouse click has happened. The time span of the fixation history shown by the scanpath can be easily adjusted. We have introduced further functions for convenience, e. g., one can draw a rectangle to select multiple indicators at once and have the according scanpaths displayed. A click on the background resets the selection and we display the heatmap again. See Figure 1 for an example on data we recorded on the homepage of Tesla (tesla.com, November 2018).

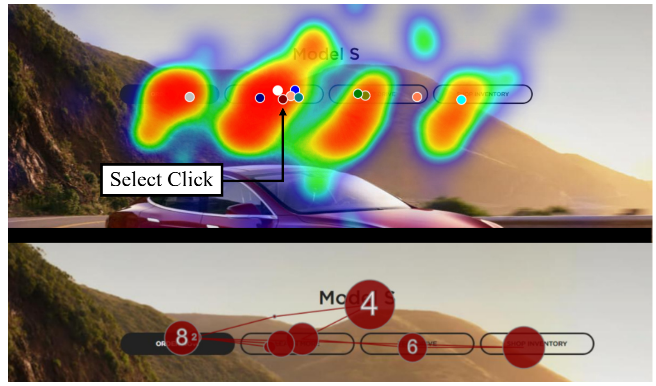

Figure 1: Combination of heatmap and scanpath

Weighted heatmap. In case of a heatmap, fixations of all users are aggregated and represented as a scalar intensity value of attention per pixel. That attention might be either a long fixation by only one user, many short fixations of many users, or something in-between. Thus, one can decide to consider fixation duration or fixation density as intensity value. There exist various problems in psychology or media science where either fixation length or the number of fixations is part of the research question. Hence, we propose to let the analyst decide how to aggregate the fixations. For each fixation, the neighborhood density is calculated and can be weighted with the length of the fixation. We use the F-measure [Sasaki 2007] to let an analyst change the importance of either density or length of fixation. See Figure 2 for the difference between both intensity computations. Normalization of the number of neighbors is achieved by dividing through the number of neighbors of the fixation with most neighbors of the screenshot. For the fixation length, we normalize by using the maximum fixation length of the screenshot.

Attention flow. The order of attention on contents is of high interest for analysts. For example, users might look at the price, photos, and ratings of a product depending on the placement of those information. Inspired from visualizations of AOI transitions, we provide a visualization of attention flow. However, instead of having the analyst defining an AOI, we provide automatic clustering of fixations to retrieve hot spots of attention. We display arrows for transitions between clusters, where color and size signify the number of transitions, i. e., dark and red means more switches, thin and green means fewer switches.

First, we cluster the fixations with K-Means [Lloyd 1982]. K-Means has the number of clusters as a parameter and uses random initialization of cluster centroids. We also offer the OPTICS (Ordering Points to Identify the Clustering Structure) algorithm [Ankerst

Figure 2: Weighted heatmap visualization

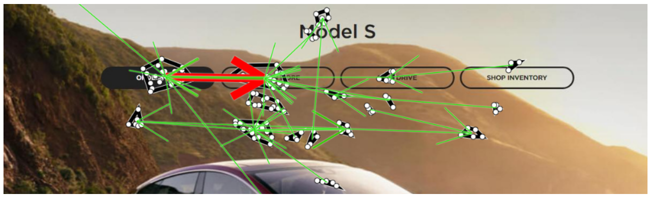

Figure 3: Attention flow visualization

et al. 1999], which has the two parameters of neighborhood radius and minimal number of points to form a cluster. Neighborhood radius defines how far a point can be from a found cluster such that it is put into that cluster. Thus, a higher value results in larger clusters. The minimal number of points to form a cluster acts as threshold for a cluster to be considered valid. In contrast to K-Means, the OPTICS algorithm leads for unchanged input data and same parameters to the same clusters at every execution, why it is preferred by the analysts in our study. We then display the convex hull of each cluster with a black line that is outlined in white color. The fixations in each cluster are displayed with white circles so an analyst can see an estimate of the number of fixations that lie in each cluster. After defining the clusters, we go over each cluster and its contained fixations. If the next fixation lies within a different cluster, a transition is recorded. See Figure 3 for an example.

3D-Scanpath. Traditional scanpaths are useful, however, they can become dense and hard to interpret while analyzing data of multiple users or a high number of fixations. Therefore, we integrate a three-dimensional scanpath visulization, where the spatial coordinates remain on the x and y-dimension, the screenshot of the Web page in the background, and the temporal property is encoded in the z-dimension (to deal with dense information). We render the screenshot of the Web page on a plane geometry in the background. In the foreground, we display the fixations with numbers indicating their index. The size of the number represents the length of the respective fixation. An analyst can manipulate the camera angle, position, and zoom level. In addition, we add dotted lines from the fixation toward the background plane. This supports an analyst in mapping fixations onto their position on the page, see Figure 4.

4 TOOL

The tool is implemented as a modern single-page application with different views, using JavaScipt, Canvas, and the ThreeJS library. The single-page architecture allows us to stick with a global scripting context and store all data consistently across the tool. Nevertheless, a visitor (usability analyst) would experience the available views as different Web pages. The analyst can navigate between the views with the global navigation on top of the Web page.

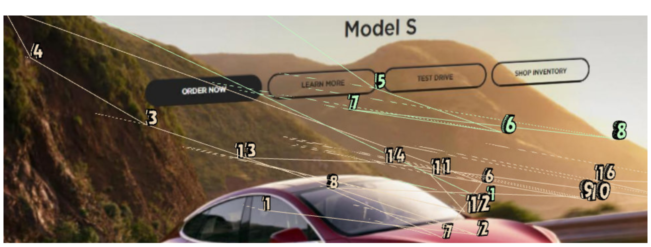

Figure 4: 3D-scanpath visualization

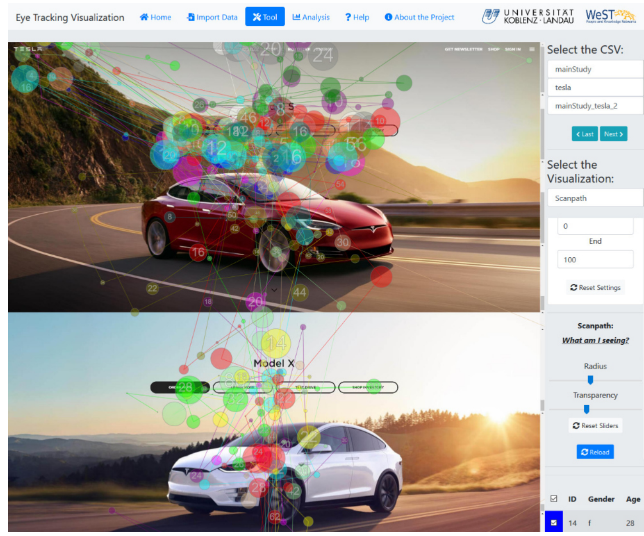

Figure 5: Screenshot of the visualization view in our tool

The initial *home view* contains a brief explanation of what the tool is about. It shows how to use the tool and redirects the user to the other views, e. g., to the *help view* when the analyst requires support in using the tool. The *data import view* allows to upload images as image files and gaze and mouse data as `.csv` files. Prominently placed in the top, the button "Try the demo data!" imports the data and the images from our dataset, that can be used to explore our tool without requiring a dataset of your own. We describe the dataset in the next section. The *visualization view* allows the analyst to select the studies that will be displayed, the visualizations to use, and parameters to adjust the visualization settings. It is also possible to filter users, and select or deselect the users, based on attributes available in the dataset, e. g., age and gender. In addition, a time window of interest can be chosen. See Figure 5, which is a screenshot of the visualization view, displaying the scanpaths of multiple users on the Tesla homepage from our dataset.

5 DATASET

To be able to demonstrate the tool and its evaluation, we have recorded a dataset of participants from our university browsing various Web sites. The dataset contains gender, age, eye correction, Web experience, and English skills of each participant, alongside the Web site addresses, screenshots, transitions, gaze and mouse data on the Web pages. The setup consisted of a laptop with a 15.6 inches screen that rendered with 1600×900 pixels, a wired mouse, and a Tobii 4C eye tracking device with 90 Hz sampling frequency. We used the EYEVIDO recording software [EYEVIDO GmbH 2020] to store all data and export the dataset. The software employs a stitching approach to create images that represent the Web pages. It separates fixed elements like menu bars and renders them separately onto the top or bottom the image [Menges et al. 2018]. We used popular Web sites (tesla.com, microsoft.com, apple.com, harvard.edu) and less known Web sites (roverp6cars.com, suzannecollinsbooks.com). The tasks for the participants ranged from reading a specific text, to finding a link or button on the page. For this, the participants were first presented with a message describing the task for each Web page and then asked to navigate the Web page like they would under everyday circumstances. In total, we recorded data from 20 participants, which is enough for eye tracking studies [Eraslan et al. 2016]. There were 25,000 fixations, 20,000 mouse movements, and 650 mouse clicks on 164 Web pages from eleven different domains.

6 EVALUATION

We evaluated the visualizations and the tool in a qualitative study. Similar to recent work in gaze data visualizations [Kurzhals et al. 2016], we recruited participants from the target audience, i. e., usability analysts. The study was performed remotely, using the benefit of the Web-based implementation of our tool. We asked the participants to open our survey form in one Web browser tab and the tool in a second tab.

Participants. We recruited six participants (four female, two male). Each participant had performed at least one eye-tracking usability study in the past. One participant even had analyzed over 20 eye-tracking usability studies. The age ranged from 25 to 59 years, with an average of 36 years. Five out of six participants provided their profession. One participant works in the field of information systems, two in psychology, one as UX-expert, and one as a scientific employee. We asked whether they are aware of the concepts of "heatmap" (6 have checked with "yes"), "fixation" (6), "area-of-interest" (6), "attention flow" (4), and "scanpath" (3). Furthermore, we asked for feedback on which visualization tools they have used so far. Answers included Tobii Studio [Tobii AB 2016], Blickshift Analytics [Blickshift GmbH 2020], and EYEVIDO Lab [EYEVIDO GmbH 2020].

Procedure. We first asked participants for demographic details, profession, and experience, as described above. Then, the participants were directed to use-case scenarios in our tool. The use-case scenarios instructed them for using the visualizations to analyze user data and answer specific questions, i. e., "how many users clicked a particular link?," "the order of attention shift for a group of users," etc. For example, the participants used the combination of heatmap and scanpath to observe the users who clicks on "Learn More" on the Apple Web site. They used the attention flow to determine on which elements the users shifted their attention after looking at the portrait of Suzanne Collins on her homepage. They used the 3D-scanpath to find out which users have seen the "Further performances" link on the Web site of the Vienna opera. The participants judged the usefulness of every visualization from 1 to 5, with 5 being very useful. Finally, the participants were asked to perform free browsing in the tool for five minutes. During that time, most participants also discovered the weighted heatmap visualization. The participants concluded the study with a SUS rating.

Results. Participants answered the use-case scenario questions mostly correct which indicates that the visualization could suffice them to understand gaze data and user behavior. With regard to participants feedback on visualizations, the combination of heatmap and scanpath were well received with the score of 4 out of 5 for usefulness. However, when selecting too many mouse click indicators, the scanpath can overwhelm an analyst as one participant commented with "I had difficulty understanding which scan paths

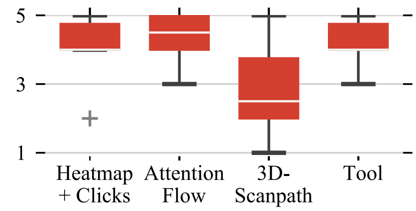

Figure 6: Usefulness of visualizations and the tool (1 lowest to 5 highest) as rated in the remote study by experts.

belonged to which participant." The attention flow received a superior score of 4.3 out of 5 on average. However, comments like "I did not understand the different colors of the attention flows." indicate that the color coding of the transition arrows might be improved. In contrast, the 3D-scanpath visualization was not well received and scored only with 2.8 out of 5 on usefulness. The feedback ranges from minor comments like "For the 3d visualization it would be helpful if you could click on the number and the corresponding line would be highlighted," over "3D-Visualization as heat map would also be nice." toward "It looks very messy." See a box plot in Figure 6 about the answer distribution.

We also asked for general feedback after the free browsing and the participants were positive in general. Some example comments are: "Weighted heatmap was the best feature, along with the clusters and attention flows! I found the visualizations very helpful!," or "The possibility to show fixations before a click is very nice." There were some negative comments, specially about the 3D-scanpath, e. g., the question on "which visualization would be useful for your field" was once answered with "All except the 3d visualization". However, another participant mentioned as most useful visualization "3D-scanpath." It is to be noted, that the 3D-scanpath was novel for all participants, whereas two participants were familiar with the concept of weighted heatmap and attention flow. Although not specifically evaluated, the weighted heatmap was popular among the participants in the free browsing task.

The functionality of the overall tool was appreciated by the participants and they rated the tool's usefulness with 4.2 out of 5. On average, SUS was scored with 70.4, which indicates a good usability of our tool [Brooke 2013]. There was explicit feedback such as "I like the filter function on the user data!", "There should be a small button "hide" to QUICKLY hide/show all visualizations." The participants also suggested some new visualizations, like "Can I combine mouse data and e. g., heatmaps?"

7 CONCLUSION

In this paper, we present a Web-based visualization tool to support eye-tracking usability analysis of Web sites. The tool offers both traditional and new visualizations to display and analyze the attention and interaction of users. We recorded a dataset of users interacting with Web sites and used it in a remote study with experts to evaluate the visualizations and the tool. The evaluation feedback was positive and encouraged us to develop the tool further to provide the community with a modern and easy-to-use platform to visualize gaze data. In the future, we aim to improve the visualizations as per usability analysts' feedback, and enhance the tool with further data processing steps, AOI editing tools, and data mining algorithms to suffice more in-depth analysis.

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