

The Linked Microposter Plot as a New Means for the Visualization of Eye Tracking Data

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Abstract

Eye tracking has been used in many scientific fields, such as behavioral sciences, education, marketing, and sports. Visualization usually plays an important role in the analysis of eye tracking data. In the past, linked micromap plots have been widely used to visualize geographic patterns of regions and subregions. Based on the idea of linked micromap plots, we introduce a linked microposter plot to visualize the eye movement pattern when people are looking at different components (such as headings, tables, figures, and different sections of text) of scientific posters. With the linked microposter plot, the eye tracking data of people looking at the various poster components can be better interpreted. The linked microposter plot provides several features that overcome some of the disadvantages of previously existing eye tracking data visualization methods.

Key Words: Eye Tracking, Visualization, Graphics, Posters, Linked Microposter Plots, Linked Micromap Plots

1. Introduction

Eye tracking is the process of measuring where people are looking at with an eye tracker device. Eye trackers were first built in the late 1800s and have been developed rapidly during the past century. Holmqvist et al. (2011) provided a comprehensive review on the history of eye trackers as well as on the principles of how they work. Eye trackers nowadays are mostly using the corneal reflection of an infrared light emitting diode to illuminate and generate a reflection off the surface of the eye (Cooke, 2005). This approach is able to track pupils precisely, therefore meaningful scene videos indicating where people are looking at are generated.

Eye tracking techniques have been applied in a variety of research fields, such as education, usability research, sports, psychology, and marketing. There exist several literature reviews focusing on the application of eye tracking, e.g., Rayner (1998) provided a comprehensive review on eye tracking for the past twenty years in reading and information processing, and Jacob and Karn (2003) provided a comprehensive review of eye tracking in human-computer interaction and usability research. Software for eye tracking data has been developed with R packages (von der Malsburg, 2015; Dink and Ferguson, 2015), Matlab toolboxes and functions (Krassanakis et al., 2014; Berger et al., 2012), Python packages (Sogo, 2013; Dalmaijer et al., 2014) and in other environments (Heminghaus and Duchowski, 2006), to detect eye movement events, to visualize and model eye tracking data, and to clean raw eye tracking data.

The eye tracking technology has become more and more affordable and accessible nowadays (Gould and Zolna, 2010). There also exists research on eye tracking for posters and related media. Barber et al. (2008) investigated posters in a computer simulated outdoor environment in order to “provide common measurement

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framework for poster panel visibility across settings and perspectives” with an eye tracking approach. Andersson (2010) looked at the effect of visual in-store advertisement designing on customers’ decisions on purchasing, with participants’ eye movement data recorded sitting in front of a computer screen. Using a mobile eye tracker, Foulsham and Kingstone (2011) investigated how people were looking at posters in an indoor environment, but with a focus on academic posters from psychology. However, none of the existing literature on eye tracking for posters has specifically discussed eye tracking visualization or adopted any new visualization techniques. In this article, we propose a linked microposter plot to visualize eye tracking data of how people are looking at posters, recorded with a mobile eye tracker.

The remainder of this article is structured as follows: We will discuss eye tracking technology and eye tracking data collection and processing in Sections 2 and 3. Eye tracking data visualization, the development of the linked microposter plot, and the construction of the linked microposter plot will be discussed in Sections 4, 5, and 6. The resulting plots will be presented in Section 7. We will finish with our conclusion and outline our future work in Section 8.

2. Eye Tracking Devices

There are two main types of eye trackers: static eye trackers and mobile eye trackers. Static eye trackers are based on a desktop, hence they are often used to study eye motion on a computer screen. Mobile eye trackers are fixed on a user’s head, so they are not limited within a restricted area and can be used for a variety of activities, such as playing soccer, driving, etc. Figure 1 shows a whole set of a mobile eye tracker equipment manufactured by Applied Science Laboratory (ASL). There is a portable Data Transmit Unit (DTU), a laptop with a wireless reception connected to the DTU, and a pair of eye tracking glasses with optics. The eye tracking glasses are the main part of the mobile eye tracker. There are two cameras on the eye tracking glasses: one tracks the participant’s eye and the other one records the environment observed by the participant.

The data generated from such equipment typically include a scene video indicating where the participant is looking at (there is only one video generated for each recording, though we have two cameras), and a data file that contains the x and y coordinates, pupil radiuses, mouse cursor positions, etc. The x and y coordinates exactly refer to where the participant is looking at on the computer screen for most static eye trackers, therefore, can be directly processed with the eye tracking data analysis software. However, for mobile eye trackers and some head mounted static eye trackers, the coordinates in the data file are meaningless. In these situations, the videos first must be processed and only the resulting data can be used for further analysis.



Figure 1: ASL mobile eye tracker equipment showing the DTU in the front, the eye tracking glasses to the right, and the laptop in the back.

3. Data Collection and Processing

The two co-authors of this article looked at a series of statistical and other scientific posters, using a 30 Hz mobile eye tracker from ASL that records 30 images per second. For each poster, the areas of interest (AOIs) were defined in advance, such as the title, logos, multiple text areas, images, and tables. For this article, two of the posters, the resulting videos, and data files here have been used. The data for Poster 1 is based on a controlled experiment. The data for Poster 2 is based on a “free-viewing” experiment where no instructions were given to the participant. The AOIs on the posters can be defined automatically with the statistical software environment R (R Core Team, 2016). The rectangles that represent the AOIs are drawn by mouse clicking two vertices and they are named by the analyst. Figure 2 shows the twelve defined AOIs of Poster 1 and Figure 3 shows the nine defined AOIs of Poster 2. The red bounding boxes outline the defined AOIs. An additional AOI, called “Blank”, contains all the empty space between these main AOIs. Poster 1 is used to test the data processing results and the validity of the linked microposter plot. The participant is timed to look at eight of the AOIs for about six seconds and at four AOIs for about two seconds. Poster 2 is used for a “free-viewing” experiment where it was left to the participant to look over the poster with the general goal to understand as much of this poster as possible. The data and video for both posters were processed in the same way. Overall, the participants looked at Poster 1 for about 56 seconds and at Poster 2 for about 80 seconds, resulting in a total of 1680 and 2400 video frames, respectively.

For further analysis, the video is broken into a sequence of consecutive video frames. Figure 4 shows an example of one of the video frames extracted from the video recorded on Poster 1. The red crosshair indicates where the participant is looking at. Since the scene is changing all the time (because of movements and head movements), the coordinates of the crosshair don’t represent where the participant is looking at on the poster. Image processing algorithms are used to automatically extract the location of the focus point at the center of the crosshair. Figure 5 shows the result of the automatically extracted focus point overlaid on the poster: the image on the right shows where the crosshair is in the original video frame and the image on the left shows the automatically extracted focus point that is overlaid with a black circle on Poster 1. Figure 6 shows all the automatically extracted focus points overlaid on Poster 1.

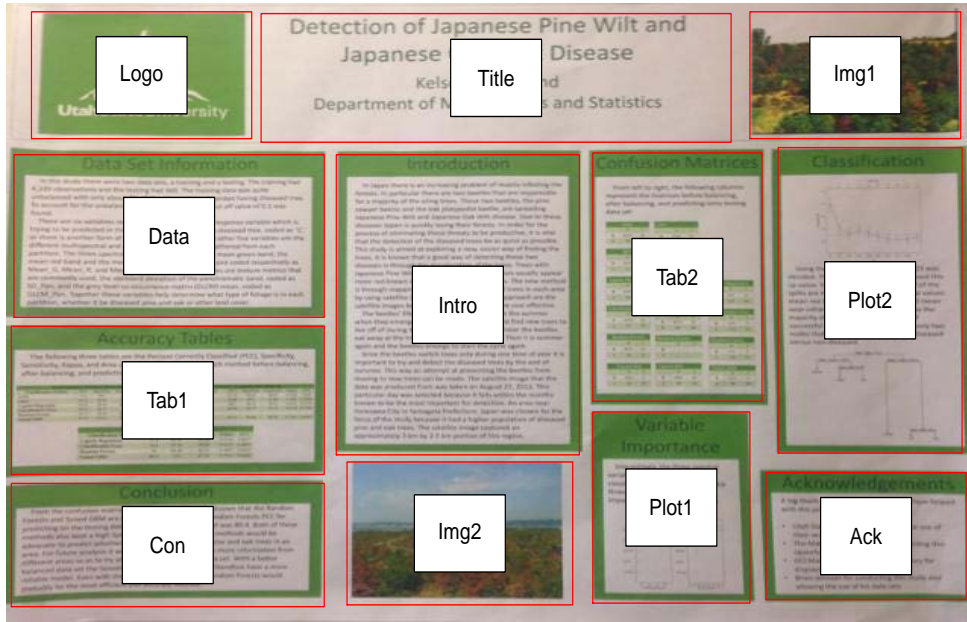


Figure 2: Poster 1 with twelve AOIs (shown inside the red bounding boxes). The abbreviations Img, Tab, Intro, Con, and Ack refer to the images, tables, introduction, conclusion, and acknowledgement in the poster.

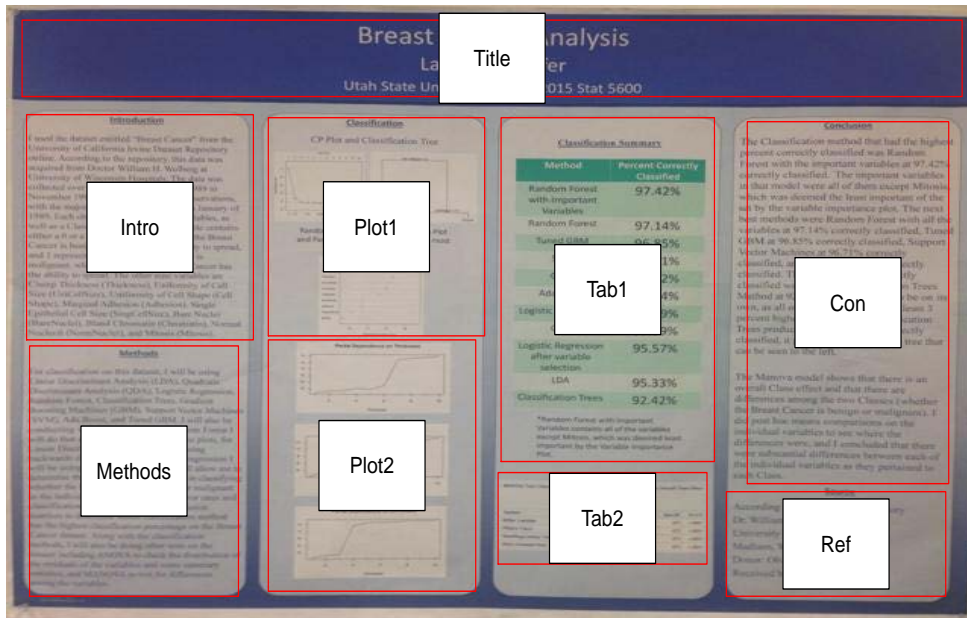


Figure 3: Poster 2 with nine AOIs (shown inside the red bounding boxes). In addition to the abbreviations used in Figure 2, Ref is used to refer to the references in this poster.

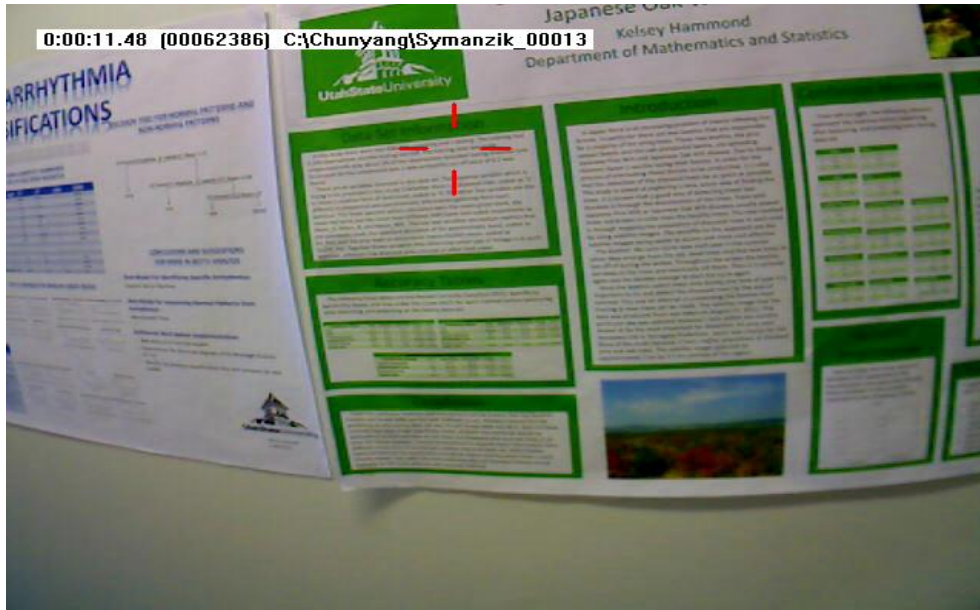


Figure 4: One of the original video frames from the video of the viewing of Poster 1. The red crosshair shows the focus point of the participant in this video frame.

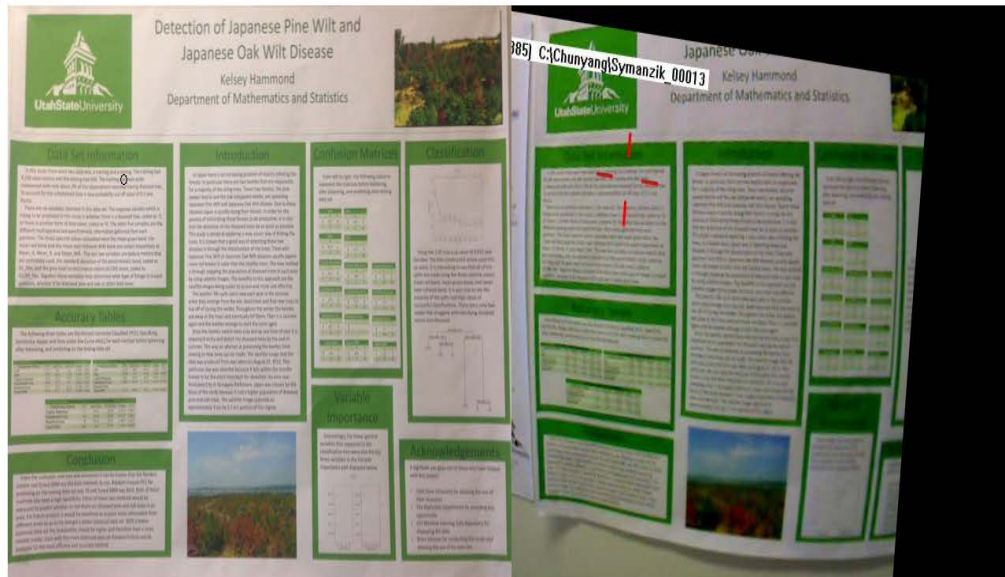


Figure 5: Automatically extracted focus point overlaid on Poster 1 (left), based on the video frame of the viewing of Poster 1 (right).

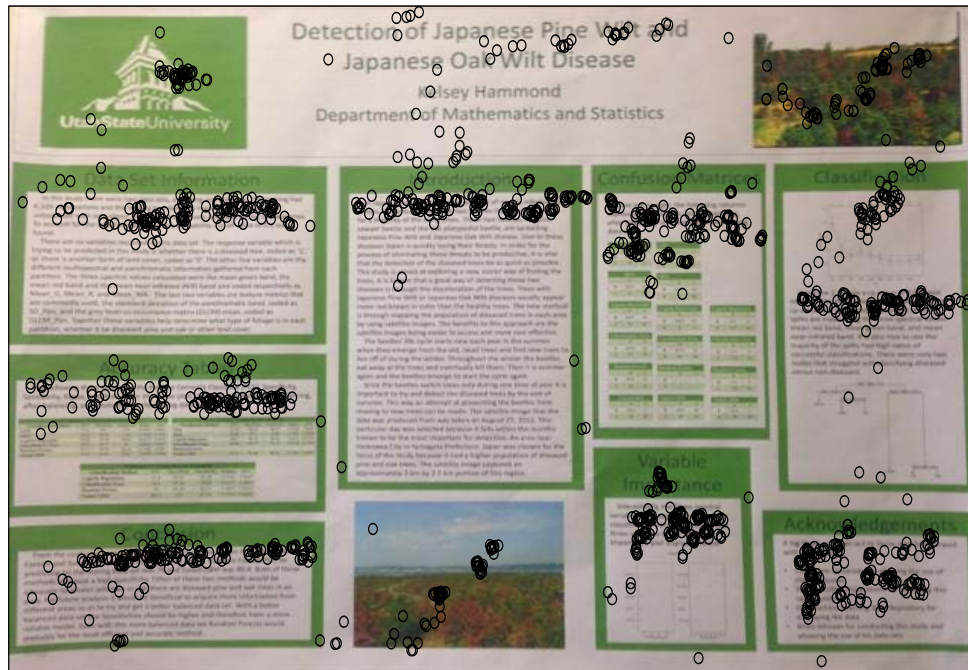


Figure 6: All extracted focus points overlaid on Poster 1, based on the video frames of the viewing of Poster 1.

4. Eye Tracking Data Visualization

Graphical methods are among the most important tools to explore eye tracking data. Common statistical graphics, such as dot plots, bar charts, and box plots, are frequently used to visualize eye tracking data. Figures 7 and 8 show examples of using dot plots and bar charts to visualize how much time the participant has spent on each AOI of Poster 1. As a reminder, data from this experiment were obtained by looking at eight of the AOIs for about six seconds and at four of the AOIs for about two seconds. Figure 9 shows an example of using box plots to visualize the pupil radius in each AOI of Poster 1. However, these three graphs are not overlapped with the poster. Therefore, it is more difficult to obtain further insights of the viewing patterns of the participant.

Attention maps are also frequently used for eye tracking data visualization (Holmqvist et al., 2011). Attention maps are usually based on heat maps or hot spot maps, using a Gaussian kernel function. Figure 10 shows the attention map for Poster 1. With the hot spots overlaid on the poster, it is quite obvious at which areas the participant is looking most frequently: the hot spots mostly appeared on the top part of each AOI, which can be explained by the viewing time limitations for each AOI. Because the participant was reading from top to bottom and left to right in each AOI, only the first few lines of text could be read in the allowed amount of time. However, only one variable at a time can be visualized in a single attention map. Also, converting numeric values into a few colors results in an immediate loss of information.

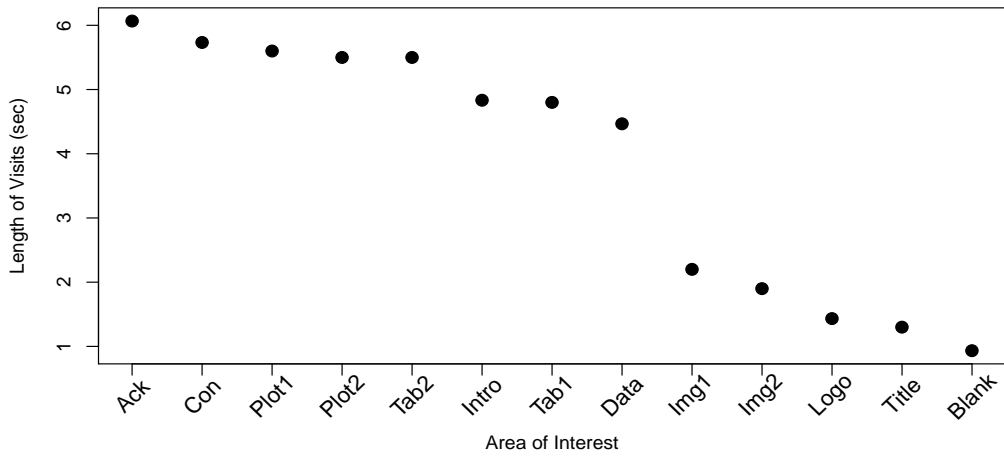


Figure 7: Dot plot: visualizing the length of visits in each AOI for Poster 1.

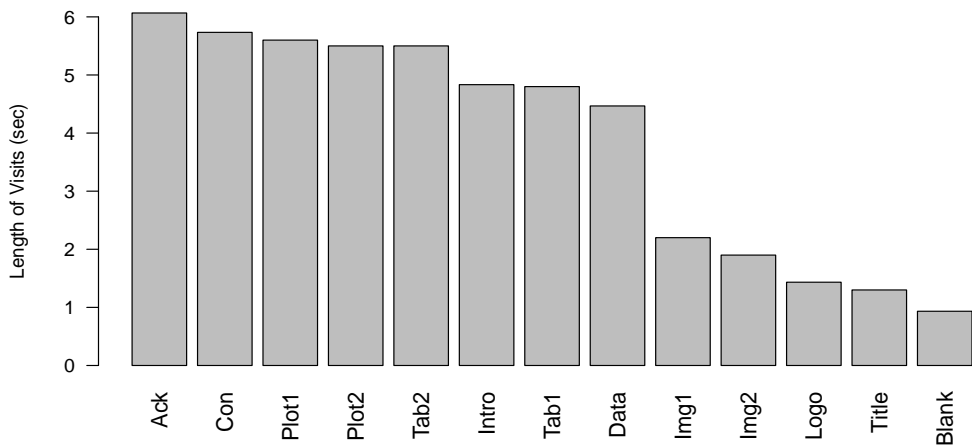


Figure 8: Bar chart: visualizing the length of visits in each AOI for Poster 1.

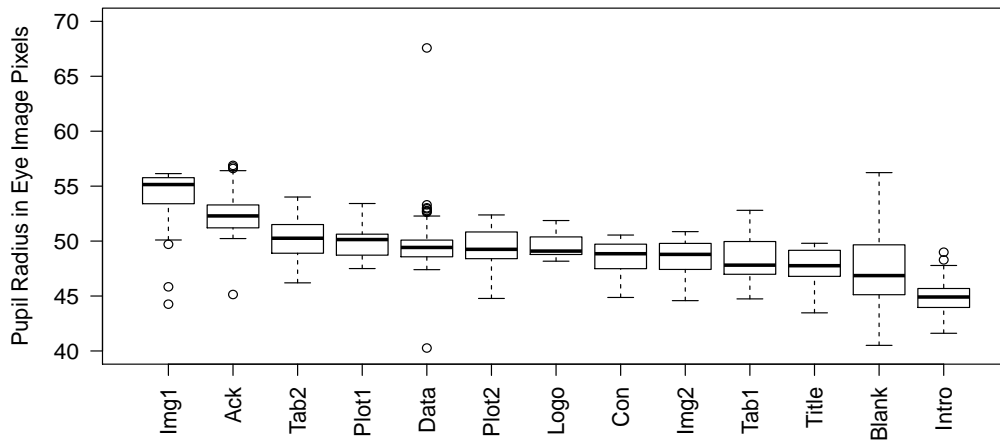


Figure 9: Box plot: visualizing the pupil radius in each AOI for Poster 1.

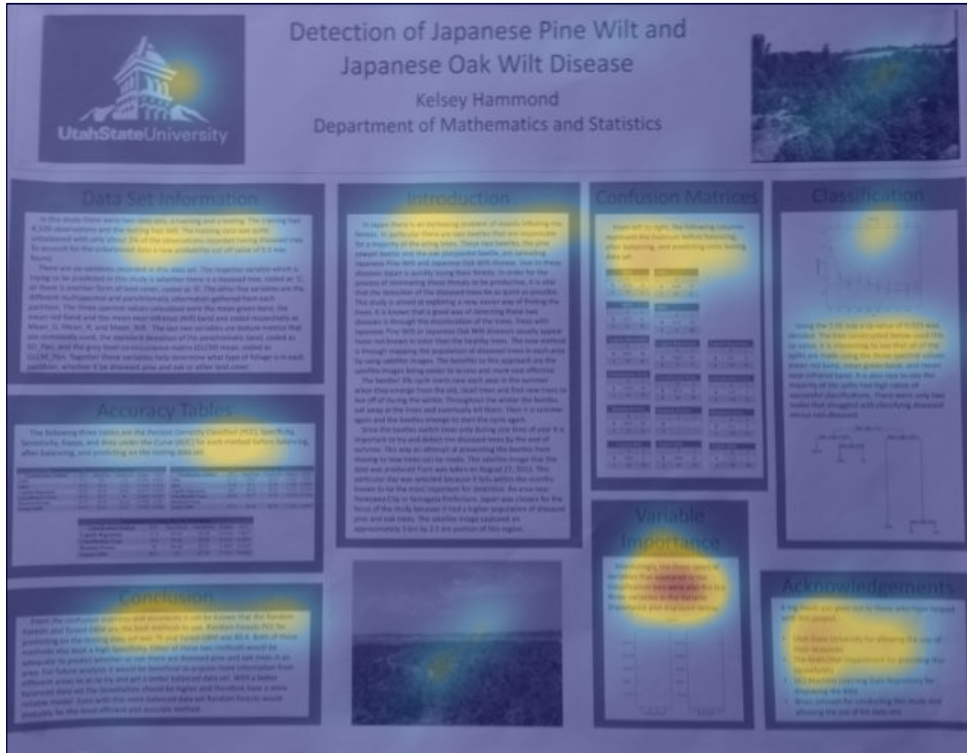


Figure 10: Attention map: hot spots that attract the participant’s attention for Poster 1.

There does not exist any type of plot that is specifically designed to visualize how people are looking at posters. To overcome the shortcomings of the commonly used eye tracking data visualization techniques, we introduce a linked microposter plot to visualize eye tracking data on posters.

5. The Development of the Linked Microposter Plot

The linked microposter plot is based on the idea of the linked micromap plot, a plot type that was first introduced in 1996 to highlight geographic patterns and associations among the variables in a spatial dataset (Carr and Pierson, 1996). It has been widely used to display geospatially-indexed summary statistics. For some in-depth discussion of linked micromap plots, the reader is referred to Symanzik and Carr (2008), Carr and Pickle (2010), and Symanzik et al. (2014). According to Carr and Pickle (2010), the micromap plot can represent any two-dimensional space, not just latitude-longitude on the Earth’s surface. Based on this idea, we can think of a poster as a map and the AOIs of the poster as the different countries or states. The AOIs of the posters are the figures, tables, text areas, titles, etc. The length of time spent and the number of times each AOI is visited, and pupil radiuses are some of the variables of interest. Other variables, such as eye movement speed, can also be visualized using the linked microposter plot. Variables can be visualized with different plot types, such as dot plots, bar charts, and box plots, in different statistical data columns, all linked to the original poster and not isolated

as in Figures 7, 8, and 9.

Compared with an attention map, the linked microposter plot is exploring selected AOIs, instead of simply looking at the hot spots. Rather than focusing on a single detailed poster, there are multiple small posters (microposters) shown in a linked microposter plot. The same colors are used to link the areas in the microposters, the names of the AOIs, and the statistical data columns. Providing small microposters on the sides, the linked microposter plot reveals the location patterns where one (or multiple) participants look at most on a poster.

6. Linked Microposter Plot Construction

Computer code to construct linked micromap plots has been available since their introduction in 1996, as summarized in Symanzik and Carr (2013). Major R code was provided in 2010 in support of Carr and Pickle (2010). With the advancement of the R computing environment, more advanced R code for the production of linked micromap plots has been developed. Two R packages, *micromap* (Payton et al., 2015b,a), and *micromapST* (Carr and Pearson, 2015; Pickle et al., 2015), have also been developed to make it easier for non-experts to produce linked micromap plots. However, the *micromapST* R package is focused on linked micromap plots for the United States. The *micromap* R package can be used for any geographic regions, but it requires new geographic shapefiles. Therefore, we developed our R code to construct linked microposter plots based on the original R code for linked micromap plots provided by Carr and Pickle (2010).

The state border data for linked micromap plots is replaced with the R border data generated by user-defined AOIs. The nation border for linked micromap plots is changed to the border of the whole poster. The poster image is used as the background image in each microposter plot. For better showing the colors, the poster image is changed to a grayscale version.

The variables investigated in our experiments for this article are the length of visits, number of visits to each AOI, and the pupil radius in pixels. Length of visits is how long the participant has spent looking at each AOI. Number of visits is how many times the participant has looked at each AOI. Pupil radiuses are measured in pixels on the eye camera and are only comparable within the same experiment with the same calibration. Though it hasn't been fully established what the changes of pupil radiuses really mean, pupil dilation has been shown to be an indication of changes in light, arousal, cognitive and emotional events, and the difficulty of the task at hand (Fong, 2012).

7. Linked Microposter Plot Interpretation

Figure 11 shows the linked microposter plot for Poster 1. The first column shows the microposters, the second column shows the color legend, and the third column shows the AOI names. The last three columns are the statistics columns. The gray shaded AOIs are the AOIs that are not of interest in the corresponding panel. The light yellow shaded AOIs are the AOIs that have been investigated in the previous microposters above the current microposter. The rows are sorted by the length of visits. Each dot that represents an AOI is horizontally aligned with its AOI name and linked through color with the AOI on the microposter. The AOIs are separated into several perceptual groups (three in Figure 11 and two in Figure 12.). Perceptual groups typically contain between two and five of the AOIs. Such a design helps the

readers focus on the values of a few mapped AOIs at once and allows to quickly identify clusters of mapped AOIs with similar values of the sorting variable (Carr and Pickle, 2010).

As stated in Section 3, the video of Poster 1 is recorded for a controlled experiment where the participant is looking at eight AOIs for about six seconds and at four AOIs for about two seconds. Figure 11 verifies that the length of visits for eight AOIs are around six seconds and around two seconds for the remaining AOIs other than the blank AOI. Although all of the AOIs are supposed to be visited only once, several of the number of visits are bigger than one. This is because the participant's visual focus point is moving from one AOI to another and may pass through other AOIs, resulting in an increased number of visits for those AOIs. To take some of these situations into account, if the length of visits is less than a threshold of 1/10 second, it does not count as a visit. The threshold can be changed by the analyst. Figure 11 shows the pupil radiuses for each AOI visualized via boxplots. The participant's pupil dilated while looking at the acknowledgement and at Image 1 of the poster, possibly because the participant saw someone he knows in the acknowledgement during the six seconds of reading and the image attracted him shortly for the two seconds of looking at it.

The linked microposter plot for Poster 2 is shown in Figure 12. This figure shows some spatial clusters of the eye tracking data that we would not be able to see in the simpler row-labelled plot designs in Figures 7, 8, and 9. We can see that the top microposter highlights the main content in the center regions of the poster, while the bottom microposter highlights the parts in the corners of the poster. This indicates that the participant has spent most of the time on the main content of the poster, i.e., both tables, the introduction, the conclusion, and one of the plots of the poster.

We are also able to visualize and compare multiple variables in a single linked microposter plot, making it easier to identify the relationship between these variables. In Figure 12, the number of visits and the length of visits doesn't seem to have a strong association. In fact, a numerical assessment confirms that the correlation coefficient r is 0.032 between these two variables. Pupil radius seems to be negatively associated with the number of visits and the length of visits, with $r = -0.43$ and -0.64 respectively (r is calculated based the median pupil radius in each AOI.).

8. Conclusion and Future Work

In this article, we used a new automatic way to extract a meaningful spatial dataset from the eye tracking video recorded with a mobile eye tracker. Details of this extraction method will be described elsewhere. To visualize the eye tracking data of how participants are looking at a poster, we introduced a new visualization tool, the linked microposter plot. We also demonstrated how the linked microposter plot effectively visualizes eye tracking data for two different posters.

Future work includes creating an R package to process the mobile eye tracking video data and then produce the linked microposter plot. More variables of the eye tracking data could be explored and displaying data for multiple participants via a single linked microposter plot could be investigated.

Eye Tracking: Looking at Poster Statistics

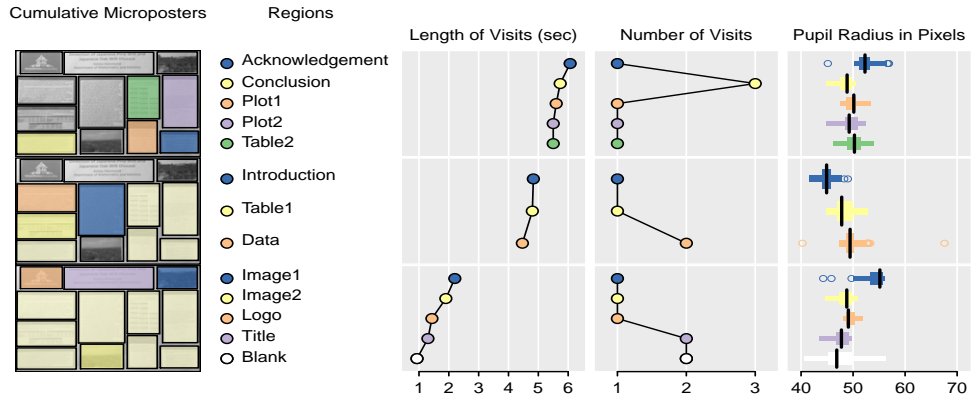


Figure 11: Linked microposter plot of the eye tracking data for the AOIs for Poster 1.

Eye Tracking: Looking at Poster Statistics

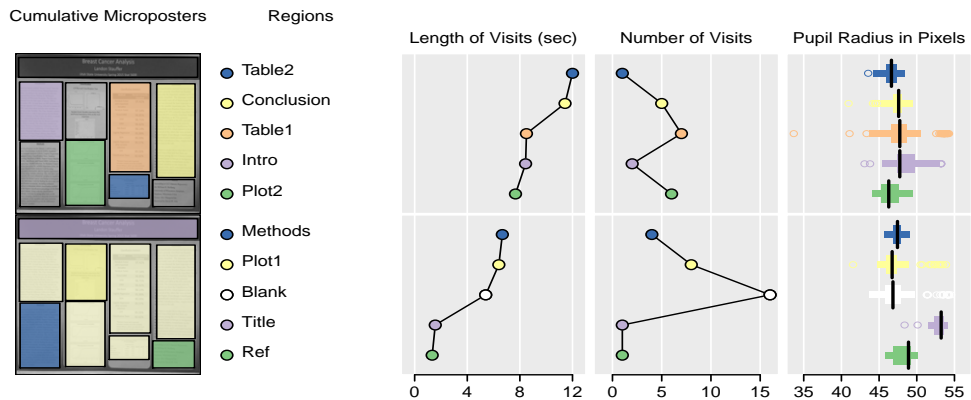


Figure 12: Linked microposter plot of the eye tracking data for the AOIs for Poster 2.

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