Visualization of Eye Gaze Data using Heat Maps

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Introduction

The relation between eye movements and internal brain processes (thinking, cognition, etc.) is known for a long time. The first eye trackers served sociologists as the “window into human mind”.

Today, usability testing is widely used to determine, for instance, the quality of web site designs [1]. Such a testing usually involves many participants having to perform a number of tasks. An experimenter observes the participants while a camera records their eye movements. The time to complete the task is usually recorded along with the type and number of errors as well as the subjective ratings for ease of use [2].

From the collected eye-movement data researchers can determine whether users were looking at the appropriate objects, differentiate reading from scanning for particular words or phrases, learn the relative intensity of the user’s attention to various parts of a web page, and find out whether the user was searching for a specific item [3].

Techniques for Eye Gaze Visualization

There is a range of techniques for visualizing the data recorded by an eye tracker. The most straightforward of those provide a simple plot of the pupil’s horizontal and vertical coordinates against time. Other techniques plot raw eye movements in 2-D with the stimulus image as the background. Again, this method is still extensively used by researchers, and is one of the easiest-to-implement techniques of the visualization [4].

More advanced visualization techniques use the so-called fixation maps to present the information in a more consistent manner (Fig. 1). Fixation detection algorithms are employed to convert the raw data into a set of fixations. Traditionally, fixations are represented by circles, and saccades are represented by lines connecting the circles.

A modern visualization technique using heat maps was derived from the fixations maps based technique (Fig. 2). Heat maps better separate different levels of observation intensity than fixation maps. Color mapping is usually selected so that the longer the observation, the warmer the color used to represent it.

A modification of the technique uses opaque heat maps with no shadow over the unobserved areas (Fig. 3). However, this kind of visualization hides details of the stimulus image. This tends to hinder the analysis.

Fig. 1. Fixations visualized as circles (University of Trier)

Fig. 2. Heat map with fixation marks (EyeTools)
In this paper, we present another version of the heat-map visualization technique. The proposed approach facilitates visualization by allowing the transparency of the heat map to depend on the gaze data itself.

Modifying Heat Maps

Heat maps provide a quick glance on the data distribution over the picture observed during an experiment. Traditionally, heat-maps visualize the background image with overlaying semi-transparent colors. Most such visualizations use red color for highlighting the most intensively observed areas, and blue or black for coloring the unobserved parts of the picture. Colors in a heat map change gradually, and the display resembles a topographic image with hills and valleys. Presenting the unobserved areas in black can be regarded as shading the image. Usually, the shadows do not totally hide the background image, but only dim it.

Our approach substantially extends the notion of heat maps. Here, the term “heat map” pertains to all the visualizations where eye gaze data adds transparency, or some color, to the background image. In our current implementation, the background can be partly or totally hidden by a shadow or fog (Fig. 4).

The initial opaqueness of an image is adjustable. Transparency can be presented in either the traditional way (using shades of gray), or employing some color scheme. In the latter case, color in a particular location conveys the intensity of the observation similar to the transparency level in a gray-scaled heat map.

The intensity is proportional to the duration of the observation. Thus, longer fixations add more transparency than shorter ones. A fixation longer than some threshold makes the display totally transparent at the location it is superimposed.

In fact, the measured gaze position during an observation contains only a single point that covers only a relatively small part of the display. Meanwhile, the actual observation involves a whole group of pixels.

Therefore, we suggest that every pixel in the heat map related to a particular gaze location “extends transparency” to the neighboring area. The radius of this area should be a few degrees of arc and subject to the user’s choice. We also propose three alternative forms for the function of the transparency distribution. One of these is a simple linear relationship, whereas the other two are nonlinear (a sum of linear and sine wave, and a Gaussian).

Visualization Options

There is a dialogue window in our software that contains the controls for setting the type of transparency and its distribution (Fig. 5). Each fixation adds a certain amount of transparency in each point of visualization. However, only the Gaussian distribution covers all the display, whereas the other distribution types affect only the area in the vicinity of the fixation. The shapes of influence for all the distributions available are shown in Fig. 6. In this figure, the x axis denotes distance from a fixation, and the y axis denotes influence on the transparency.
The controls of the second group (Transparency creation) allow adjusting the influence of each fixation on the transparency. Sensitivity ($S$) denotes the radius of influence (Linear and Linear + Sine distributions), or variance $\sigma^2$ (Gaussian distribution).

Brightness level ($BL$) is used as the gain for the distribution functions. It shows the minimum fixation duration ($FD$) that makes the view totally transparent at the place of its occurrence.

Hiding level ($HL$) denotes the initial level of the shadow’s or fog’s opaqueness. Totally hidden background of the view corresponds to $HL$ of 100%.

The meaning of the last control (Slicing level) depends on the value of the option Slicing. By default, it is None, which means that transparency just changes by one of the distribution rules and no slicing is applied (Fig. 7a). With the option Steps checked, transparency is shaped like terrain steps (Fig. 7b). The width of each step equals the value of Step level in pixels. The transparency rate of a step is the average of all pixels in the step.

With the option Mask checked, transparency lower than the value of Mask level is not applied to the visualization (Fig. 7c).

Finally, with the option Relief checked, the calculated transparency is applied only if its value is a multiple of Relief level. This makes visualization similar to the topographic map (Fig. 7d).

The procedure for setting the transparency can be illustrated through an example. Suppose that the recorded data has $N$ fixations. Transparency $T_i$ of a single pixel at distance $D$ from the $i^{th}$ fixation in the Linear distribution is calculated using the following expression:

$$T_i = T_{i-1} + \begin{cases} \frac{S - D}{S} \cdot \frac{FD_i - HL \cdot BL}{BL}, & \text{if } (D \leq S), \\ 0, & \text{if } (D > S). \end{cases} \tag{1}$$

For the Gaussian distribution, $S$ is equivalent to $\sigma^2$.

The multiplier before the exponent keeps $T = 100\%$ when $FD = BL$ for any value of $S$ and $BL$:

$$T_i = T_{i-1} + \frac{FD_i - HL \cdot BL}{BL} \cdot e^{-\frac{D^2}{2S}}. \tag{2}$$

In all the expressions, $T_i$ is the cumulative transparency after the first $i$ fixations. Before any fixation can contribute to transparency, $T_0 = HL$. The value of $T_N$ cannot be less than 0, or greater than 1.

Hiding can appear as a shadow or fog. It is defined via the option Opacity. From the implementation point, shadowing means covering the background picture in black, whereas fogging is covering it in white.

The Other options group contains the rest of the controls. If the flag Use color scheme is checked, the semi-transparent areas appear in color. The coloring schemes are displayed in the drop-down list next to this flag. The left-most color is applied to the areas with low transparency, whereas the right-most color is applied to the fully transparent areas. Current implementation of our software supports the following color schemes:

- Blue – Green – Red – White;
- Blue – Green – Red;
- Blue – Red;
- Green – Yellow – Red – White;
- Green – Yellow – Red.

If the Separate areas flag is checked, a fully or partly transparent area is separated by an inverted-color boundary from the area with the initial transparency level. However, this flag has no effect when applying any of the slicing options.

If the Draw fixation dot flag is checked, small white or black dots representing the fixations are displayed. Finally, if the Show hint flag is checked, a hint appears when moving the mouse cursor over the display that shows the transparency level and coordinates of the cursor.

Conclusions

This paper proposes a technique to facilitate visualization of eye gaze data gathered during both basic experimental studies on eye movements and usability studies on products and displays. The technique is an extension of the heat-map based visualization method. Its
unique feature is that eye gaze data modulates the transparency of heat maps.

In other words, eye gaze is allowed to add transparency to the shaded background. This way the details of less relevance are hidden (using either shadows or fog) from the view, whereas more intensively observed areas become more conspicuous through increased transparency.

Usability studies on various products proved our version of the heat-map visualization technique quite useful for researchers [5, 6].

References


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