Eye Tracking Analysis of Preferred Reading Regions on the Screen

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Abstract
We report on an exploratory study analyzing preferred reading regions on a monitor using eye tracking. We show that users have individually preferred reading regions, varying in location on the screen and in size. Furthermore, we explore how scrolling interactions and mouse movements are correlated with position and size of the individually preferred reading regions.

Keywords
Eye tracking, reading, mouse movements, scrolling

ACM Classification Keywords
H1.2. Information Systems: Models and Principles. User/Machine Systems.

General Terms
Experimentation, Measurement, Human Factors

Introduction
It is imperative to understand how people view Web pages in order to inform design. While viewing Web pages, one of the most frequent activities is reading, i.e., fixating the text with our eyes in a characteristic manner and understanding it. But apart from the movements of our eyes that can be detected by eye trackers [2], we interact in further ways with a com-

puter while reading. For example, we scroll from time to time and move the cursor using a mouse. Such kinds of interactions can tell us something about how the user is reading.

In this paper, we analyze preferred reading regions on the screen. When users read documents or longer Web pages, they usually scroll in order to move the text being read into their preferred reading area on the screen. Our goal is to explore and analyze these regions using eye tracking in order to find characteristics of reading regions that are similar or different across users. Further, we aim at estimating a user's individual reading region without using an eye tracker, just by observing mouse movements and scrolling interactions. Eventually, such information will help us in the future to acquire implicit feedback for information retrieval while viewing documents as it can be done using eye tracking directly [3].

Closely Related Work

Mouse movement behavior and its relation to eye gaze has been analyzed in previous research. For example, Cox and Silva [4] studied this relation in an interactive task where participants had to select menu items. They found that the mouse cursor is often used to tag interesting targets that have been looked at before. Later, Rodden et al. [6] studied the relationship between mouse movements and gaze on search result pages. They identified three important types of mouse movements differing between individuals: 1. following the eye gaze only vertically, 2. following it also horizontally, and 3. marking snippets of the text. This research is particularly interesting because it shows that mouse movements can be very informative with respect to the user's focus of visual attention on the screen.

Hornbæk and Frøkjær [5] analyze reading behavior of long documents in more detail and explore the effect of different document visualization techniques. They observed by looking at scrolling behavior that documents are sometimes read linearly, sometimes parts are skipped, and sometimes parts are read multiple times. Atterer and Lorenzi [1] make use of this information and implemented a browser plug-in that stores display time and visualizes it next to the browser scrollbar.

Research Questions

In the following, we are reporting on an initial exploratory study where we had the following research questions:

1. How is visual attention generally distributed on the screen during reading?
2. What is the nature of variation across users?
3. Is there a relationship between mouse movements and the distribution of visual attention on the screen?
4. Is there a relationship between scrolling behavior and the distribution of visual attention on the screen?

Experimental Design and Procedure

In order to answer these questions, we designed a user study to collect data from eye tracking, mouse movements, and scrolling interactions from participants engaged in two different reading tasks. For both tasks, we first gave them a concrete task description and then provided them with preselected, long documents they had to use.

The first task was a *shopping task* where the participants had to find and select components for a new computer system by meeting pre-given constraints concerning performance and price. We provided the participants with one over 60 screen pages long document containing all needed information in table form (compare figure 2). We asked them to find eight components for the new computer system like a CPU, a hard disk drive, a mainboard, etc. The one pre-given document contained one table for each component type. Each table had several columns. The first column always contained manufacturer and type information, the last column contained the price, the columns in between contained further component specifications.

The second task was a *reading task*. Here, the participants got precise topical information needs and had to read through four provided long documents in order to find facts satisfying their information need. One of the topics was about visual perception of animals while the second dealt with thermoregulation mechanisms of animals. In both cases, we provided them with the same set of documents, i.e., four Wikipedia articles about snakes, bees, dogs, and seals which they viewed serially. Each article was about 12 screen pages long and contained passages with relevant information about both topics. However, most of the documents' content was irrelevant to the tasks.

Apparatus

During the entire experiment, gaze data from the participants was recorded using a Tobii 1750 desk-mounted eye tracker (see http://www.tobii.com) having a screen size of 17" and a resolution of 1280x1024 pixels. Additionally, the experimental workstation comprised a common keyboard and a standard mouse with a scrolling wheel.

All documents were presented in a browser (Firefox) that contained additional functionalities to log mouse movements and scrolling interactions. Further, for some of the participants, we recorded screen videos capturing everything happening on the screen.

Participants

Five participants performed the shopping task whereas 15 participants performed the reading task (no participant performed both tasks). They were university graduate and undergraduate students majoring in a variety of different subjects. The completion of the shopping task took around 10 minutes per participant; finishing the reading task (both topics together) took around 30 minutes.

Results

Research Question 1

"How is visual attention generally distributed on the screen during reading?" Figure 1 depicts the distribution of gaze on the screen during the reading task across all 15 participants. Vertically, gaze is concentrated around the middle of the screen. The distribution of the recorded gaze data is very similar to a normal distribution; no significant difference could be observed (one-sample Kolmogorov-Smirnov test).

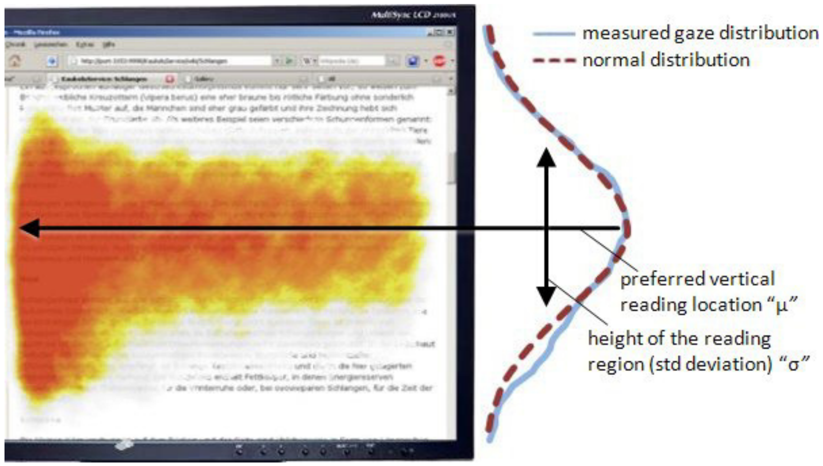

figure 1: Distribution of visual attention on the screen for the reading task.

As figure 1 shows further, over the left border of the text, gaze is much more vertically spread out than over the middle and the right border of the text. In order to get an explanation for this observation, we analyzed the screen videos taken from 5 of the participants. The screen videos together with an overlay of the recorded gaze positions at every point in time revealed two behaviors during the reading task: concentrated reading and scanning.

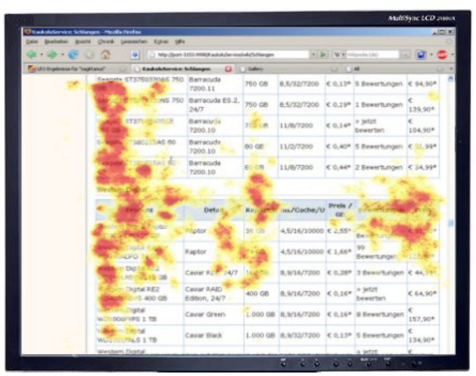

figure 2: Distribution of visual attention on the screen for the shopping task.

Since the pre-given pages for the reading task were relatively long (around 12 screen pages) but only contained a few passages relevant to the task, scanning behavior occurred in order to find the relevant parts of the document. During scanning behavior, the participants mostly looked at the beginning of the lines and quickly scanned downwards. For this, they usually used the entire height of the document's viewport (i.e., the area inside the browser window showing the document). In contrast, during reading behavior, the participants looked over the full length of each line (not only their beginnings) but only used a vertically narrow part of the screen.

The distribution of visual attention looks different for the shopping task as shown in figure 2. However, analyzing the screen videos with an overlay of the recorded gaze positions showed a similar pattern as for the reading task: the left border of the text, i.e., the headlines and the first column of the tables, were used for scanning and to find relevant parts of the documents. If a relevant part was found, then the remaining columns with more specific information about the product were focused and moved vertically into the middle of the screen.

Overall, while viewing long documents, the gaze distribution looks like a T-shape rotated by 90° to the left. The stem comes from reading behavior, whereas the bar comes from scanning behavior.

Research Question 2

“What is the nature of variation across users?” In order to answer this question, we analyzed heatmaps visualizing the gaze locations for individual users. We found that there is a surprisingly large variation across users, mainly with respect to two different parameters depicted in figure 1: the vertical preferred reading location μ (i.e., the location of the peak of the individual distribution), and the vertical spreading σ of gaze around that preferred location (i.e., the standard deviation of the individual distribution). We observed a continuous variation across users concerning both parameters. Two exemplary individual gaze distributions in the form of heatmaps and diagrams from the reading task are shown in figure 3. Participant 1 (top) has a broad preferred reading region (medium μ, large σ), whereas the visual attention of participant 2 (bottom) is rather narrowly distributed (large μ, small σ).

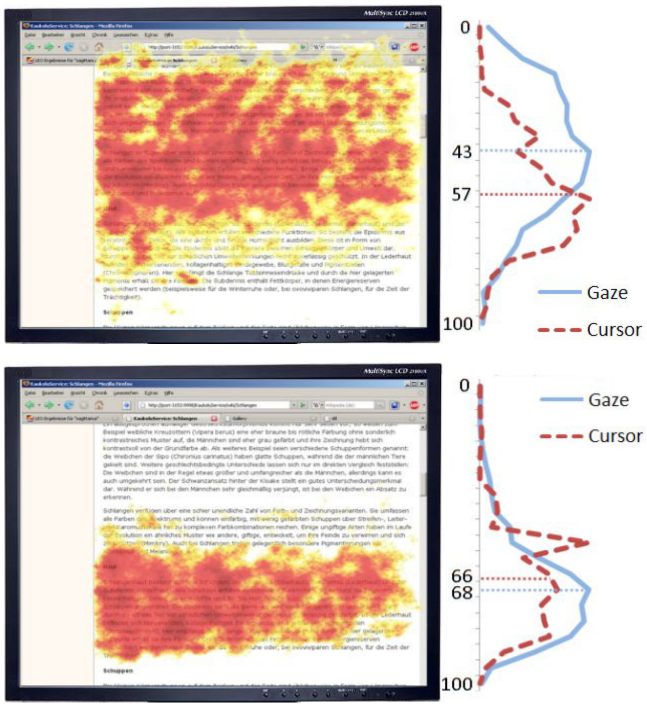

figure 3: Participant 1 (top) has a broad preferred reading region in the upper and middle part of the screen. Participant 2 (bottom) has a narrow preferred reading region in the lower part of the screen.

Research Question 3

"Is there a relationship between mouse movements and the distribution of visual attention on the screen?" An exploratory analysis of the data from the reading task (15 participants) revealed that for an individual participant, the distribution of the vertical cursor position over time is relatively similar to the vertical gaze distribution, particularly with respect to the mean values of the distributions. Ignoring two "outlier" participants for whom both distributions did not match well, we determined an average difference of 8.0% of the screen height between the means of both distributions for the reading task (standard deviation = 5.9%). For example as shown in figure 3 (top), the difference between the two means for participant 1 (who was one of the two outlier participants) equals 57% - 43% = 14%; for participant 2 (figure 3 bottom) it equals 2%. Therefore, the mean of the vertical cursor position distribution may serve as a good estimate for the individually preferred vertical reading location μ of a user.

Research Question 4

"Is there a relationship between scrolling behavior and the distribution of visual attention on the screen?" In this respect, our assumption was that the distance of a typical scrolling action might reflect the amount of vertical spreading of the gaze distribution (i.e., the height σ of the reading region, see figure 1). To give two extreme examples: on the one side, a user scrolling every once in a while for one full screen height might always read from the top of the screen to the bottom and, thus, might have high vertical gaze spreading (similar to participant 1 in figure 3 top). On the other side, a user scrolling very frequently for only a few lines might have very narrow vertical gaze spreading (like participant 2 in figure 3 bottom).

We computed the Pearson correlation coefficient between the mean scroll distance and the standard deviation of a participant's gaze distribution on the screen. But this resulted in a very low correlation coefficient of r = 0.02. However, from an analysis of the screen videos it was evident that scrolling distances are very different for reading behavior compared to scanning behavior. Also, as discussed earlier (research question 1), the attention distribution for scanning and for reading behavior is different: the preferred reading region seems to be mostly used for reading behavior and not so much for scanning behavior. Therefore, after ignoring frequent and long scrolling interactions that typically belong to scanning behavior rather than to reading behavior, we found a slight correlation between the mean scroll distance and the standard deviation of a participant's gaze distribution with a correlation coefficient of r = 0.28.

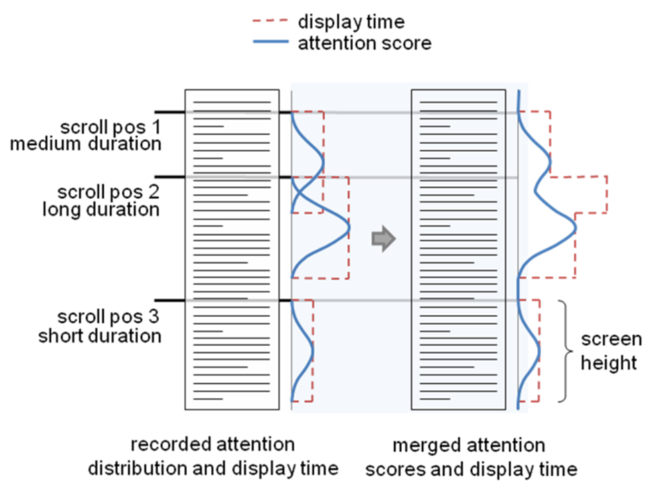

figure 4: Future application: approximate what parts of a document the user has most likely paid attention to.

Overall, the average scroll distance of a user is informative with respect to the vertical spreading σ of the user's gaze distribution on the screen during reading. However, there is also much noise in the data, coming from navigational interactions with the document that occur when the user is scanning text.

Conclusion and Outlook

In summary, our exploratory study shows that visual attention is not evenly distributed on the screen. Users rather have their individual preferred reading regions when working with long documents. Vertically, visual attention can be approximated by a normal distribution specified by two parameters: the preferred vertical reading location μ and the amount of vertical spreading σ. It seems reasonable to estimate the value of μ by the user's individual average vertical cursor position on the screen during reading. The parameter σ might be approximated by the individual average height of scrolling actions during reading.

Being capable of precisely approximating what parts of a document on the screen have been read by the user is valuable as implicit feedback for information retrieval as well as for improved interaction with documents. Figure 4 sketches how an attention score can be computed considering display time of visible parts of a document and the user's preferred reading region on the screen. Based on this data, it can be estimated what parts of a long document have been read intensively. When opening the same document at a later time, this information can help to refresh the reader's memory about what has been relevant when having viewed the document before. Alternatively, such attention scores could be applied as implicit feedback in information retrieval scenarios.

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