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Using Scarf Plots to Visualize Moment-to-Moment Visual Search Behavior on Websites

Des *scarf plots* pour visualiser la dynamique des comportements visuels de recherche d'information sur sites Web

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Despite a large number of metrics and eye-tracking data visualization techniques allowing us to study information search on the Internet, the moment-to-moment dynamics of this process has not been taken into account. Therefore, the aim of this paper is to show the interest of visualization methods such as scarf plots. An adaptation of these visualizations has been developed and applied to a dataset of 46 participants who have performed an information search task on a website. Compared to the techniques usually used, our approach allows us, on the one hand, to illustrate the information search behaviors of each individual in one figure (the total duration of the search, the path of the web pages, the number of web pages, the duration of web page exploration, the areas of interest explored, etc.), and on the other hand, to juxtapose several individuals, thus allowing us to easily compare and categorize them.

CCS Concepts: • **Human-centered computing** → **Visualization**; *Web-based interaction*; *Hypertext / hypermedia*.

Additional Key Words and Phrases: visualization, eye tracking, scarf plot, transition, information search, web, moment-to-moment behavior

Malgré un nombre important de métriques et de techniques de visualisations de données oculométriques permettant d'étudier la recherche d'information sur Internet, la dynamique de ce processus reste inexploitée. Par conséquent, l'objectif de cet article est de montrer l'intérêt de méthodes de visualisation telles que les *scarf plots*. Une adaptation de ces visualisations a été développée et appliquée à un jeu de données de 46 participants ayant réalisé une tâche de recherche d'information sur site Web. En comparaison des techniques habituellement utilisées, notre approche permet, d'une part, d'illustrer les comportements de recherche d'information d'un individu en une figure (la durée totale de la recherche, l'arbre des parcours, le nombre de pages vues, la durée de consultation de chacune des pages, les aires d'intérêt consultées, etc.), et d'autre part, de juxtaposer plusieurs individus permettant ainsi de facilement les comparer et les catégoriser.

Mots-clés additionnels : visualisation, oculométrie, graphique en écharpe, recherche d'information, web, dynamique des comportements

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1 INTRODUCTION

In recent years, eye-tracking has been widely used in the field of information search on the Internet [1, 3, 14, 16, 20]. It allows us to track and record continuously, and in real time, the position of the individuals' gaze on a web page. Two common events are identified from the recorded data: fixations and saccades [11].

The fixation is a static state of the eye that makes it possible to collect visual information. The saccade is a rapid movement of the eye between two fixations. It is used to move from one source of information to another. The main

measures used to characterize these two events are the number of fixations and their duration as well as the amplitudes of saccades [13]. In order to characterize the visual search of an individual, descriptive statistics such as the mean, the median or the standard deviation of the fixation times, or the saccade amplitudes, are calculated either by page or by area of interest (AOI).

These global indicators, can be represented by plots (e.g., histograms, box plots, scatter plots, line plots, etc.). Other visualizations exist for eye-tracking data. Each of these visualizations falls into one of two categories: those based on points (point-based) and those based on areas of interest (AOI-based) [4].

Point-based visualization techniques rely essentially on the coordinates and temporality of the eye-tracking data. The two most widely used techniques are attention maps and scanpaths. As an illustration, in a systematic review of the literature published in 2020, 30% of the papers listed (from 2004 to 2019) used attention maps [20]. These visualization techniques are used to compare, for instance, different strategies among groups of individuals [10].

Attention maps are spatial visualization techniques where the fixation density of several individuals is aggregated and color-coded according to the number of fixations and their duration. The most common form is the heatmap (see Figure 1, A). This visualization colors the areas with a graduation from green to red, red representing the region most fixated. There are other types of visualisations such as the focus map, which masks in black the areas that are not looked at, and lets appear the looked ones (see Figure 1, B).

Scanpaths (or gazeplots) are a spatio-temporal visualization technique. In contrast to the attention map, which is only spatial (see Figure 1, C), it presents all the fixations and saccades. Each fixation is materialized by a circle and each saccade by a line that joins two fixations. For the fixations, two other pieces of information are also represented graphically: the size of the circle which increases with the duration of the fixation and the sequence order of the fixation which is indicated by a number inside each circle.

Attention maps can highlight the most viewed areas by aggregating a large number of users in the same visual space. Scanpaths, on the other hand, are quickly cluttered, even unreadable, as the number of users increases. Nevertheless, the scanpaths have the double advantage of preserving individual specificities and showing the temporality of events.

AOI-based visualization techniques rely on the definition of areas of interest, that is, the division of the visual environment into zones. These areas can be defined semantically [3] (i.e., source of information relevant or not for the task), grid-based [21] or data-based [7–9].

There are several AOI-based visualizations that use two-dimensional plots in which one axis represents the progress of time and the other axis the areas of interest in which the gaze can stay (e.g., time plot, parallel scanpath visualization, AOI rivers (Figure 2)) [4]. These visualizations provide a fine-grained way of studying the behavior of small groups of individuals. However, these classical examples were not designed to compare a large number of individuals.

Scarf plots illustrate gaze transitions among AOI on a timeline. This visualization has been applied to different eye-tracking datasets: visual interactions between a speaker and a listener [19], scientific reading [24] and the study of subway maps [5]. However, this type of visualization has not been used in the context of information search on the Web.

The aim of this paper is to propose a new visualisation method which would allow us (1) to represent multiple eye-tracking and information search metrics on web pages from a large number of participants in a single visualization, and (2) to make groups of individuals salient.

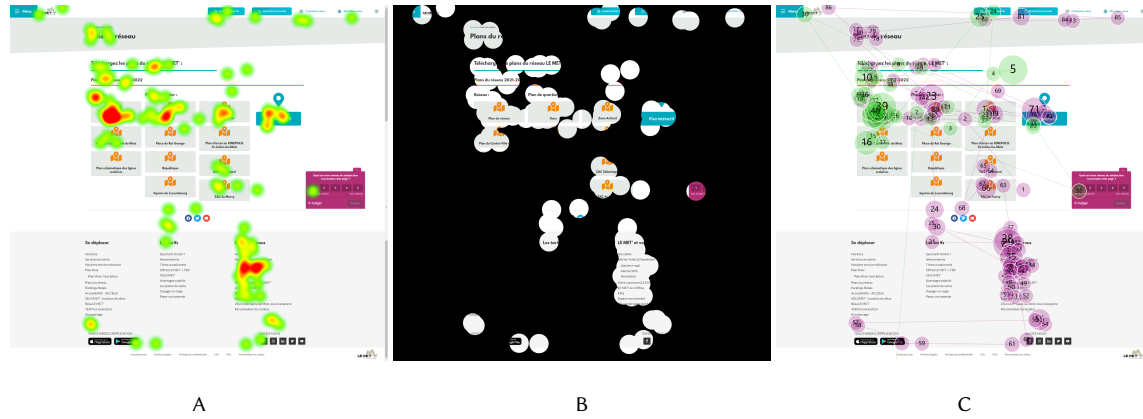


Fig. 1. The same data set represented by a heatmap, a focusmap and a scanpath.

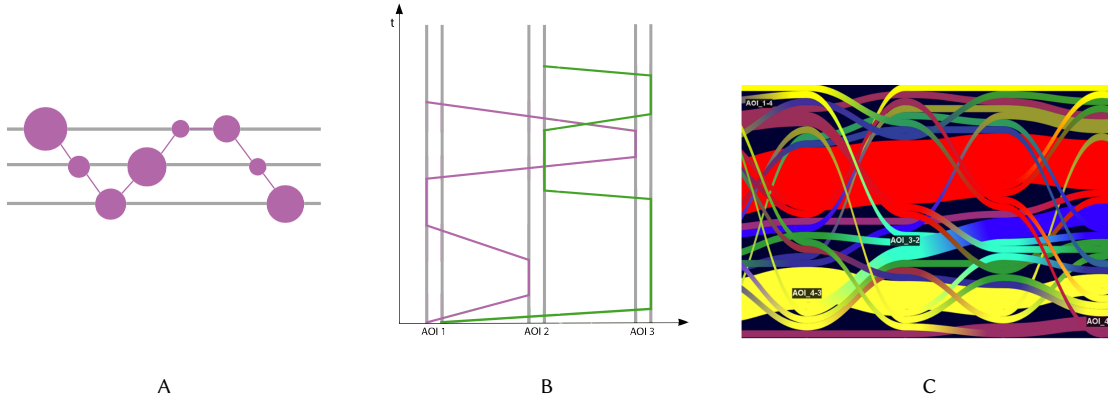


Fig. 2. Illustration of a timeplot, parallel scanpath and AOI rivers (based and taken from [4]).

We have chosen to start from the scarf plots, which in our opinion allow us to fulfill these two objectives, and to adapt them to the specificities of information search on the Web. The main specificity of web search that makes visualizations complex is that a search for information requires browsing a collection of web pages. Moreover, it is difficult to visualize multiple pages for a group of individuals with scarf plots as well as heatmaps and scanpaths. The visualization inspired by the scarf plots that we propose in this study overcomes these drawbacks.

2 METHOD

2.1 Participants

A total of 46 participants were recruited at the University of Lorraine in order to carry out an information search task on a website. The sample was composed of 15 men (32.61%), 29 women (63.04%) and 2 others (4.35%), with an average age of 28.5 years ($SD = 14.7$ years). Eighty percent of the participants were students.

A large majority of participants used to search for information on the Internet several times a week or every day (93.4%), and felt comfortable doing this activity (89.1%). They searched on the Internet using a tablet or a smartphone

rather than a computer (78.3%). More than seventy percent of participants had previously visited websites similar to the one proposed in this experiment. However, over three-quarters of the participants had never visited the selected website.

2.2 Material

The website of the metropolis of Nancy¹ was selected in this experiment because it is mainstream, that is, used by a large population and does not require specific knowledge (see Figure 3).

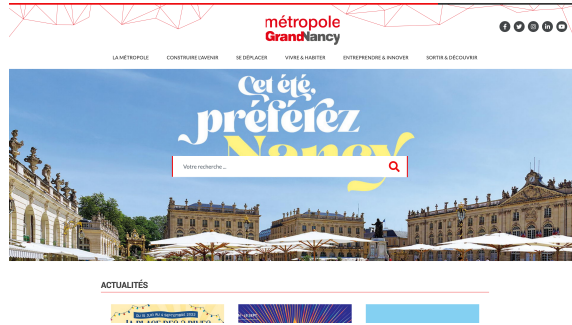


Fig. 3. Home page screen of the selected website.

The apparatus was located in a usability lab at the University. The participants were provided with a computer screen (21.5 inch with a 1920x1080 resolution), a wired mouse and a keyboard to interact with the website.

A Tobii Pro Nano bar was placed under the participant's screen in order to capture their gaze. The eye tracker was run by the v.1.8.15.0 firmware and the setup and calibration was performed using the v.2.2.10 Eye Tracker Manager software. The sampling fixations was set to 60Hz.

A laptop was used with the Tobii Pro Lab software (v.1.194) in order to conduct the experiment, to collect and manage the data.

2.3 Procedure

The test sessions were run individually in the observation room of the usability lab.

The aims of the study and the procedure of the experiment were presented to the participants and they were asked to complete a consent form in duplicate.

Once the individuals were settled, the eye tracker calibration phase began. Then, a written reminder of the general instructions was displayed on the monitor and the information seeking task phase started. This phase was conducted as follows: the search instruction appeared, followed by a fixation cross to be looked at, after which the web browser was launched with the home page of the website. The participants' task consisted in finding the name of a waste center that was open on Sundays in the metropolis of Nancy. Upon completion of the task, participants were invited to give the answer orally.

At the end of the experiment, the participants filled out a questionnaire concerning their socio-demographic information and the time spent on Internet. Finally, participants were thanked for their participation.

The experiment lasted an average of 9 min and 56 s ($SD = 3$ min and 40 s).

¹<https://www.grandnancy.eu>

2.4 Data preparation and analysis

The Tobii Pro lab software was used to define and export several AOI for each web page. The relevant links for the success of the information search task were defined as AOI. The other areas of interest consisted in the header, content and footer of the web pages where relevant links were also located in order to provide additional information. Figure 4 illustrates the AOI of one of the web pages.

To analyze the data from this experiment, we proceeded in two steps: an analysis using the common visualizations (heatmaps and scanpaths) in eye-tracking followed by an exploratory analysis of the moment-to-moment behaviors with an adapted version of the scarf plot.

The construction of the adapted version of the scarf plot was developed using the programming language R [18], ggplot2 [22] and the Tidyverse packages [23].

3 RESULTS

Forty-four participants (95.7%) successfully completed the information search task. Two participants (4.3%), who did not succeed, were excluded from the analyses. Successful participants took an average of 1 min and 21 s ($SD = 50$ s; $Min = 26.76$ s; $Max = 3$ min and 34.55 s) to complete the task.

As shown in Table 1, the number of pages viewed by participants varied from 3 (24 participants) to 17 (1 participant). Several paths have been taken to find the information. However, the most used path was the sequence "07-16-23".

3.1 Heatmaps and Scanpaths

Heatmaps and scanpaths provide a quick way to see where participants focused their attention. As shown on Figures 5 and 6, fixations remain primarily focused on the navigation menu links of the home page (page 7). On subsequent pages, participants took more time exploring the content of the page in search for information and links relevant to the task (see Figure 5 and 6, pages 16 and 23).

Heatmaps (Figure 5) are used to show the most viewed areas in each page. On the home page, for example (Figure 5, page 7), the relevant link is located in the menu at the top of the page. This visualization fits very well with a large number of participants as is the case here. However, the absence of a temporality indicator does not allow us to visualize the dynamics of the visual behaviors.

Using the same data, the scanpaths (Figure 6) also show that the visual exploration is mainly focused on the top of the home page. But it also highlights that a certain portion of the visual exploration is made outside of these main areas, giving a slightly more accurate idea of how the web pages were actually explored. However, the large number of participants makes this visualization particularly unreadable. The numbers inside the circles that give information on the sequence of the fixations, as well as their size, are information that cannot be displayed. All of this does not make it possible to highlight individual differences that might exist, or even possible groupings of individuals according to their patterns of exploration.

3.2 Web Scarf Plot

3.2.1 The big picture. The web scarf plot describes how each individual has searched for information on a website in a single figure (Figure 7). The timeline for each participant gives us information such as the duration of the search, the path taken, the number of pages consulted, the duration of exploration for each page and the areas of interest explored.

Table 1. Number of participants having visually explored the different sequences of web pages. Each number under the clicstream column corresponds to a specific web page.

Clickstreams	N
07-16-23	24
07-29-56-17	3
07-29-42-56	1
07-29-56-20	1
07-29-56-21	1
07-32-16-23	1
07-01-07-16-23	1
07-02-07-16-23	1
07-01-08-56-19	1
07-24-07-16-23	1
07-29-42-56-17	1
07-29-42-29-56-22	1
07-16-23-35-16-23	1
07-29-41-29-38-29-42	1
07-01-08-29-56-18-56-17	1
07-29-36-22-36-29-56-17	1
07-29-38-29-39-29-39-29-56-17	1
07-08-07-29-56-17	1
07-29-71-29-42-29-06-65-09-14-06-71-56-17-56-17-56	1

The web pages materialized by rectangles have been color-coded. Each web page is assigned a specific color. This way, it is possible to know which pages have been browsed and for how long.

Inside each colored rectangle (i.e., the web pages), we find the AOIs previously defined. The AOIs delimiting the zones of the web page (i.e., header, content, and footer) are each placed on a different line. The visual exploration of

a given AOI is materialized by a black vertical line. When relevant links are seen in an AOI, they are represented by yellow vertical lines. The number of vertical lines indicates the duration of fixation.

In Figure 7, participants were sorted on the basis of three criteria: the path taken, the duration of the total search and the time spent on the home page. This organisation facilitates the identification of similarities and differences in visual search behaviors of the participants. The web scarf plot also allows us to visually compare users both on the basis of their visual exploration and on more global metrics such as the duration of the search, the number of pages consulted, etc. Finally, it allows us to easily notice patterns at an inter-individual or individual level. If we look at the upper part of that figure, we have the 24 participants that went through web pages 7, 16 and 23. Their path is identical, and as it is easily noticeable, some of those participants took approximately the same time to find the information they were looking for. But others spent a lot more time on page 23. And when looking at the figure, we easily observe the differences between the first 24 participants and the rest of the group.

3.2.2 Focus on four participants. Even if this type of visualization lets you put all the participants and a certain number of metrics in the same illustration, it is also possible to zoom in on specific participants in order to compare their behavior more closely at different levels. To illustrate this, we chose to focus on four participants: 4, 39, 44 and 5 shown in Figure 8. These four participants are globally equivalent in terms of task duration. However, they differ on other metrics.

It can be noticed that participant 4, starting from the home page, consults different pages in comparison to the three other participants, who follow strictly the same path.

Participant 39, even if he visits the same pages and in the same order as participants 44 and 5, does not spend the same amount of time on each of these pages, with a very long visit duration on the home page, and conversely a very short duration on the final page.

Participants 44 and 5, differ in their visual exploration of the pages. On the home page in particular, we can notice that participant 5 focuses almost exclusively on the header AOI, then exclusively on the content AOI, before clicking on a link. Participant 44, on this same page, switches many times between these two AOIs.

4 DISCUSSION

In this paper, we have presented an extension of the scarf plots — web scarf plots — to support the visual analyses of information search behaviors on websites. This visualization proposes to depict the moment-to-moment of one or more individuals' visual behaviors across web pages.

This visualization makes it possible to compare several users based on metrics commonly used in the field of human-computer interaction such as the total task duration, the path and the duration of each page exploration [21]. Moreover, two other metrics from the visual behavior have been integrated to this visualization: the visited AOI, and on specific AOI, the relevant link that has to be clicked-on to accomplish the task. This was made possible by the way the AOIs were coded, which was done on two levels of granularity. AOIs were defined in order to divide the whole visual environment into three areas: the header, the content and the footer of the page. Then, in each of these AOI, the hyperlinks relevant for the task were defined as AOI. These two levels of coding were built semantically so as to be generalized to all the pages that could be visited. All this allows a simplified and efficient visualization of these visual behaviors.

In the field of information search on the Internet, to be able to classify users could facilitate the study of the dynamics of the visual search behaviors, the variability of those behaviors as well as the discovery of behavioral patterns. The

identification of behavioral patterns through classification could also allow to adapt an interface to different users or to predict a risk of failure, which could complement the usual approach based on global indicators [2].

The way the metrics have been encoded to allow this visualization could be given as input to quantitative methods such as T-patterns [15] or classifiers (e.g., k-Nearest Neighbors [6]). However, the objective of this study was to produce a visual classification tool. Indeed, the fact of classifying individuals according to certain indicators brings out visual groupings. In our example, by sorting the participants according to the path taken, the duration of the task, the number of pages consulted, the optimal path to find the requested information becomes obvious. A different sorting could have been done, for example, by sorting the participants only on the duration of the task, in order to see whether the number of pages correlates or not with task duration.

In the future, other eye-tracking metrics could be used such as those proposed by Poole and Ball [17] and Ball and Richardson [1]: the coloring of the saccade/fixation ratio; the time to first fixation; the total length of scanpaths, which accounts for the efficiency of visual exploration; the spatial density, which accounts for a more or less direct visual search. In the same way, the coefficient K [12], which accounts for the focal or ambient attention, could be added.

Still using eye-tracking data, where we had divided the AOI into relevant and other links, it would be possible to add a third category with the surrounded links. These links are those that are located in the same cluster as a relevant link. This would allow us to discuss the strategy of how a link is consulted, or even the significance of the links.

Finally, it would also be possible to add other more conventional indicators in the field of human-computer interaction, such as clicks and scrolls, which reflect the effort made by the individual. This would lead to a more complete view of the user experience.

5 CONCLUSION

In this work, we propose a visualization tool, the web scarf plots, which is an adaptation of the scarf plots to visual information search on websites. Despite the exploratory dimension of this work, it opens many perspectives, notably by the possible addition of indicators characteristic of visual exploration on the one hand or of user experience on the other hand. This tool can be used to look differently at the collected data. It could thus be used by researchers who wish to report on behavioral dynamics, as well as by user experience experts.

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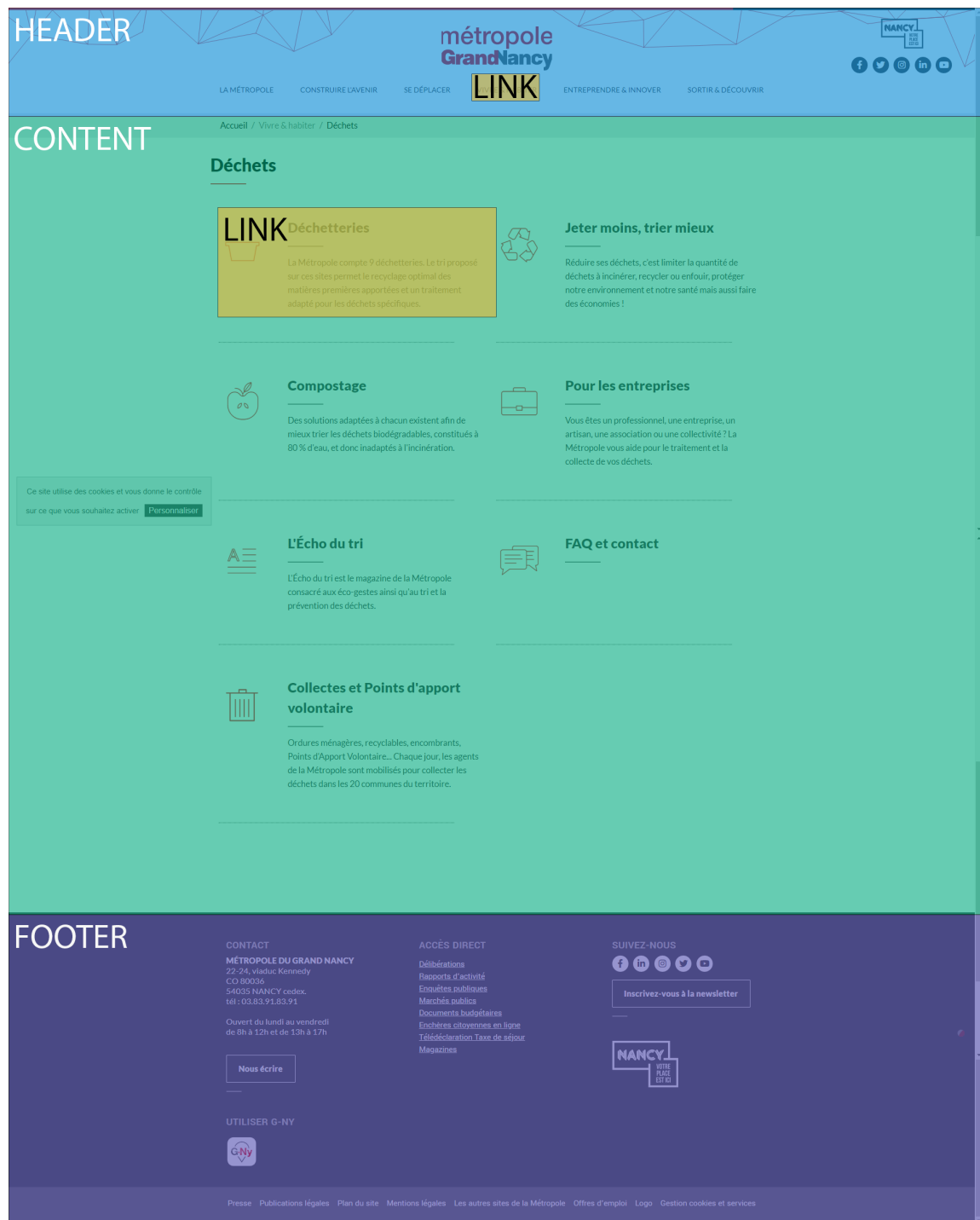


Fig. 4. Example of AOI definition for a given web page.

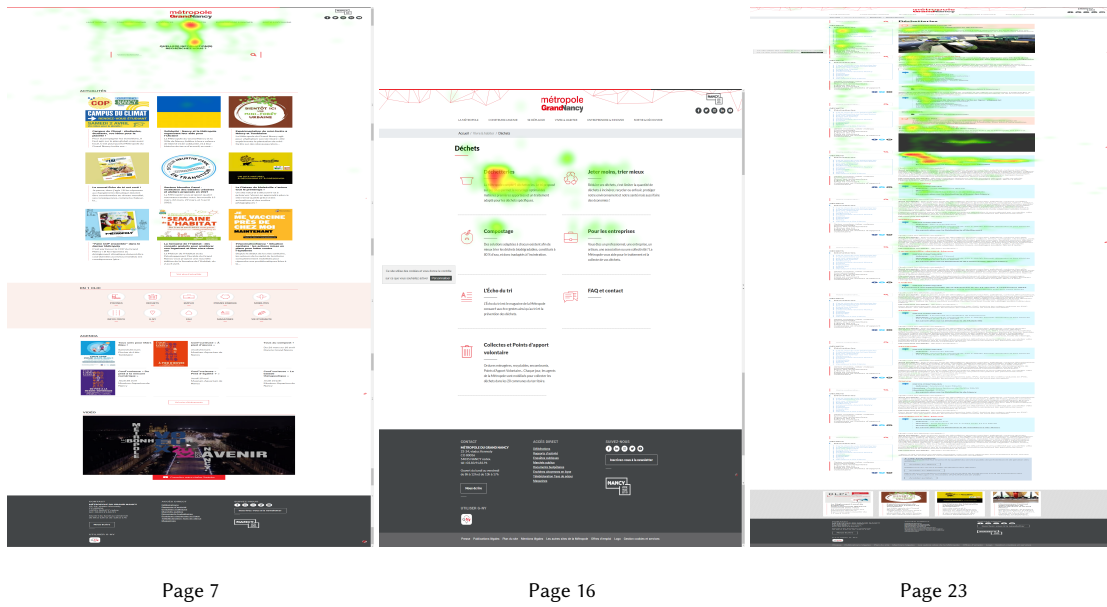


Fig. 5. Heatmaps of the most used path (n = 24)

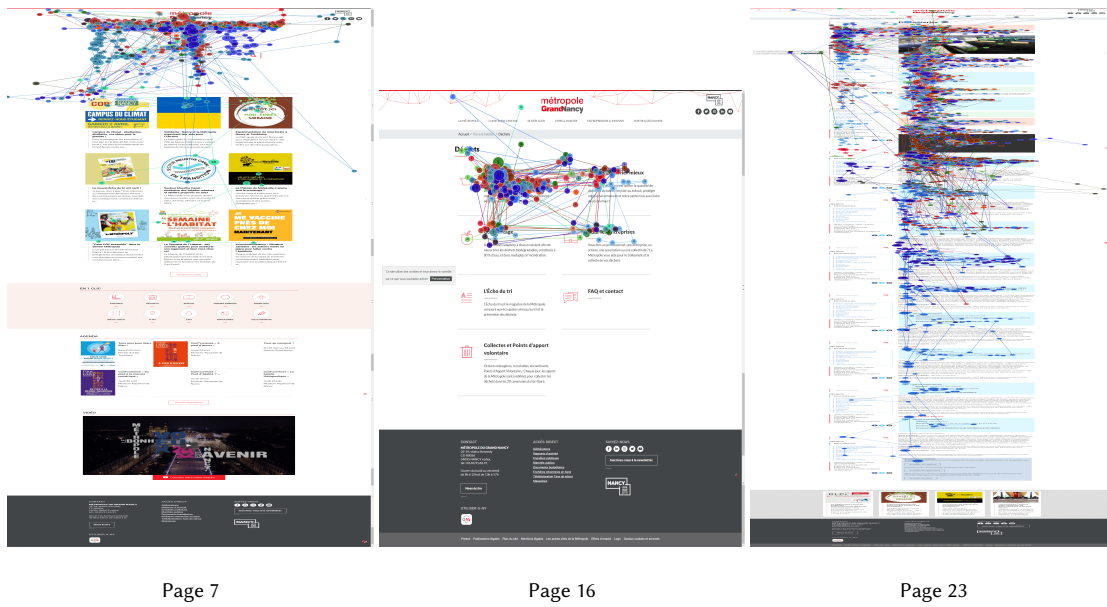


Fig. 6. Scanpaths of the most used path (n = 24).

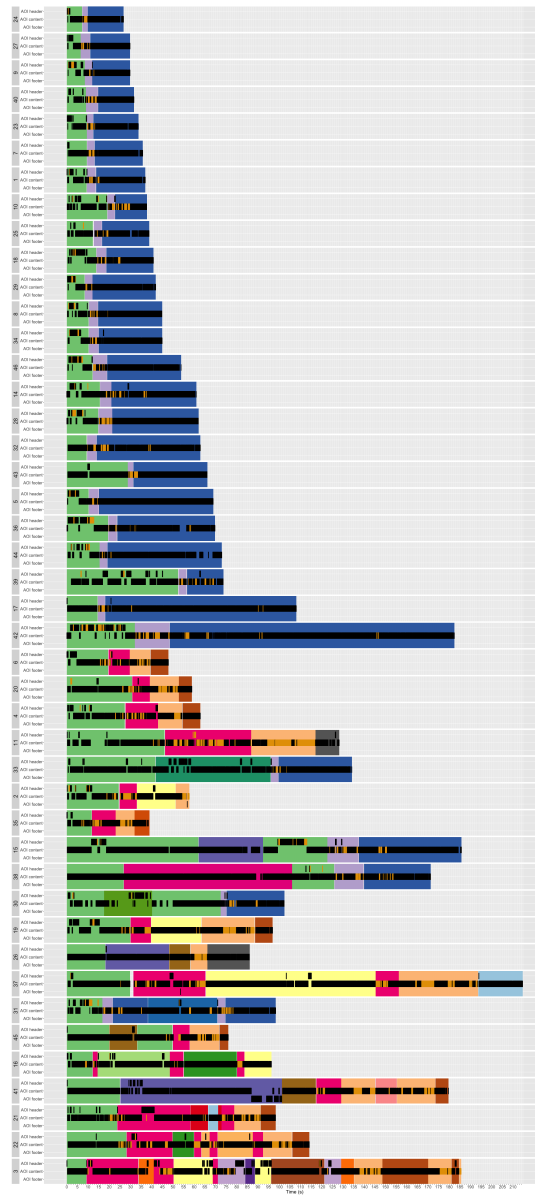


Fig. 7. The big picture of the web scarf plot (n = 44).

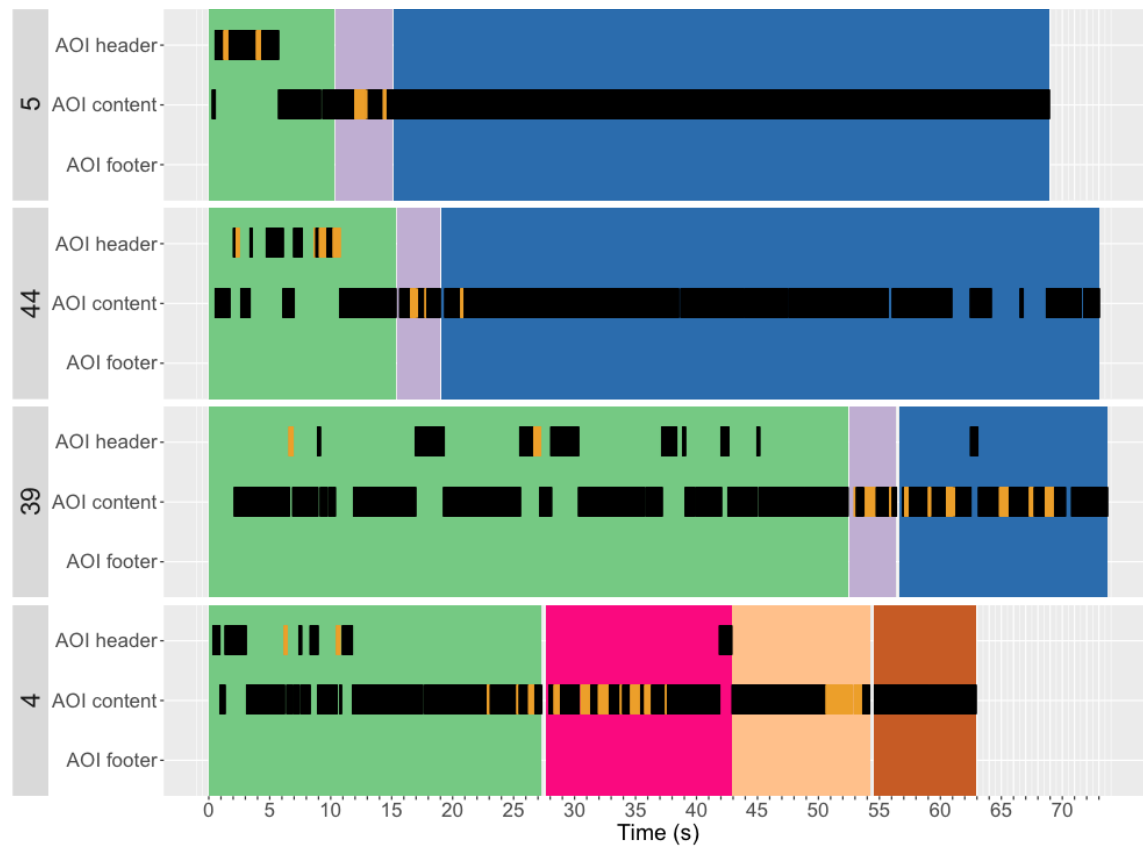


Fig. 8. The scarf plot for four participants (5, 44, 39, 4).