Iris: A Tool for Designing Contextually Relevant Gaze Visualizations

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ABSTRACT

Advances in eye tracking technology have enabled new interaction techniques and gaze-based applications. However, the techniques for visualizing gaze information have remained relatively unchanged. We developed `Iris`, a tool to support the design of contextually relevant gaze visualizations. `Iris` allows users to explore displaying different features of gaze behavior including the current fixation point, duration, and saccades. Stylistic elements such as color, opacity, and smoothness can also be adjusted to give users creative and detailed control over the design of their gaze visualization. We present the `Iris` system and perform a user study to examine how participants can make use of the tool to devise contextually relevant gaze visualizations for a variety of collaborative tasks. We show that changes in color and opacity as well as variation in gaze trails can be adjusted to create meaningful gaze visualizations that fit the context of use.

CCS CONCEPTS

• **Human-centered computing → Visualization toolkits**;

KEYWORDS

Eye-Tracking, Gaze Visualizations, Design

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1 INTRODUCTION

Gaze visualizations help to illustrate how we look at a visual scene by displaying graphical representations that are based on the gaze coordinates collected from an eye tracker. They reflect how we process visual information and they can be designed to illustrate a wealth of information, such as how long we look somewhere, where we looked before, and if we revisit the same place. However, no tools currently exist that provide researchers with easy and full control over the design of the visual characteristics of gaze visualizations. We developed a system called `Iris` that provides users with direct control over the graphical features that constitute gaze visualizations in order to give them the ability to construct more meaningful, insightful and novel gaze visualizations.

Effective gaze visualizations serve at least two important roles. First, they support behavioral analysis by visually representing how a participant attended to objects and looked at a visual scene. Commercial analysis packages from companies including Tobii[1], SR Research[2], iMotions[3], and MeasuringU[4], as well as open source projects [Mital et al. 2011; Tang et al. 2012], can be used in this way. However, these packages only provide variants of two basic visualization techniques: gaze plots and heat maps. Gaze plots display saccades, or connections between multiple fixations, to illustrate eye movements over time; whereas heat maps aggregate gaze information over time by displaying fixation duration and coverage – or how long someone looked at particular areas of a visual scene. While these techniques visualize important eye movement behaviors and attentional patterns, there are a wide range of other possible visualization techniques that may be applied to further improve our understanding of gaze behavior.

A second role that gaze visualizations serve is found in Human Computer Interaction (HCI) research where developers visualize real time eye movements to support remote collaboration [Jermann et al. 2012]. This technique involves collecting eye movement data from one participant and displaying a visual representation of their gaze patterns on the shared work space of another participant. These "gaze-based interventions" can either support real time or asynchronous collaboration (e.g., by using pre-recorded gaze coordinates), and they have been shown to improve coordination and communication in a variety of tasks including: visual search [Brennan et al. 2008], problem solving [Bard et al. 2014; D'Angelo and Gergle 2016], distance learning [Schneider and Pea 2013; Sharma et al. 2016], medical training [Sridharan et al. 2012], trip planning [Qvarfordt and Zhai 2005], and programming [Bednarik et al. 2011; D'Angelo and Begel 2017; Stein and Brennan 2004]. In these studies, gaze is typically represented as a single point on the screen that reflects the gaze coordinate stream interpreted from the eye tracker. However, recent studies have shown that the specific design choices made when creating the gaze visualizations impact the types of inferences a partner makes and affects how they are used to support coordination [D'Angelo and Begel 2017; Li et al. 2016; Newn et al. 2017; Zhang et al. 2017]. Gaze visualizations can be designed to elicit different types of collaborative behavior such as searching together or independently [D'Angelo and Gergle 2018], and paying

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[1]http://www2.tobiidynavox.com/gazeviewer/
[2]http://www.sr-research.com/dv.html
[3]https://imotions.com/eye-tracking/
[4]https://measuringu.com/eye-tracking/

attention to the specific context of use when designing a gaze visualization can result in more effective support for collaboration (e.g., [D'Angelo and Begel 2017]).

While the literature reveals clear advantages to designing gaze visualizations specific to the task at hand, researchers have been limited in their capacity to do so easily. The exploration of novel gaze visualizations has been limited largely due to an inability to easily change the design of a gaze visualization together with the time-consuming process of evaluating new visualizations. To address these challenges, we developed `Iris` – an open-source system that allows users to quickly experiment with different visual representations in real time using their own eye movements. The `Iris` system supports rapid exploration of the design space for gaze visualizations and makes interacting with eye movement data broadly accessible.

In this paper, we: (1) describe the `Iris` system, (2) discuss the importance of contextually relevant gaze visualizations, and (3) present a think-aloud evaluation to demonstrate the ways in which users design unique gaze visualizations for different tasks.

2 IRIS SYSTEM

We developed `Iris` as an open source project[5] implemented in Windows Presentation Foundation (WPF), a graphical system which uses C# and XAML. The goal of the system is to make gaze visualizations easier to develop and customize along a number of different dimensions including: size, color, number of previous fixations, opacity, and style (see Figure 1). `Iris` allows users to manipulate the representation of their eye movement information in real time and apply their visualization to any screen-based context. They can also record and view the same sequence with different visual representations in order to compare different designs. The direct manipulation interface makes `Iris` easy to use and the flexibility of editing features gives users the ability to create novel visualizations.

Eye movement coordinates are recorded by a Tobii 4C remote eye tracker. A looping function called every 10 milliseconds then passes the current gaze coordinates as parameters to update the visualization; this function also handles gaze recording, playback, and pausing. To manipulate the gaze visualization, users can pause the looping function and then make the desired changes to the visual representation. They can then restart it to view the new visualization in real time.

`Iris` provides several basic elements for visualization that represent three main features of eye movements and their representation: *fixations*, *saccades* and *style elements*.

- The *fixation* feature can be adjusted by clicking and dragging on the fixation point, which allows users to adjust the outer radius, inner radius, and opacity. For example, using this technique a shadow of any length can be extended to better highlight movement or a pointer can be filled with an adjustable zoom lens to visually magnify the area currently in focus (see Figure 1, left side).
- The *saccade* feature is illustrated as a line connecting fixations points. The line element has a short memory of past gaze positions, and the line's length can be changed to customize the amount of previous gaze data represented by dragging its endpoint. The physical shape of the line can also be changed – allowing users to adjust the starting width, ending width, starting opacity, ending opacity, and length (see Figure 1, middle). In `Iris`, a slider is available to adjust how long the fixation duration should be before it is displayed as a previous fixation point. This allows for long trails connecting past points of focus, or short updates that focus more locally on the current gaze location.
- The users can further customize the gaze visualization with adjustments to a number of *style elements* including: smoothness, opacity, blur, and color. These features give users the ability to manipulate visual attributes not available in existing software (see Figure 1, right side). For further details on the system implementation please see an earlier non-archival description [Brewer et al. 2018].

Combining all of these elements gives the user creative control over the visual representation and provides a platform for designing new gaze visualizations. `Iris` not only lets users create gaze visualizations quickly via direct manipulation, it also directly shows how the visualization reacts to the user's eye movements (see Figure 2). The flexibility of the editing features allows users to iterate quickly and the simple interface encourages creative exploration. As eye tracking becomes more ubiquitous, `Iris` allows users to explore communicating with eye movements through gaze visualizations.

3 CONTEXTUALLY RELEVANT GAZE VISUALIZATIONS

The general goal of `Iris` is to support the development of gaze visualizations designed to meet the needs of a specific context and task. These designs are not intended to be generalized to all applications, rather they are intended to be unique to a specific context. For example, to understand how a student reads a document, it is useful to display connections between previous fixation points to best illustrate aspects of the comprehension sequence. However, this same technique would not be helpful for giving directions in a dynamically changing video because the information is time dependent and rapidly changing. We describe this approach as "contextually relevant design".

A contextually relevant design approach requires that researchers consider each aspect of the context including: the relationship between the collaborators (e.g., a jointly coordinated activity vs. a leader/follow or expert/novice setting), the content of the task (e.g., visually complex and rapidly changing display content vs. a simple and static diagram), and the task requirements (e.g., what information do the collaborators need to complete the task?). Each of these aspects can be used to inform the design of the visual representation. While further research is needed to establish specific design guidelines for gaze visualizations, `Iris` provides a platform for researchers to explore the possibilities and expand our understanding of gaze visualization design.

As one example, an `Iris` user can combine features to best create a unique visualization that meets specific needs. If the user wants to mark important areas on a map with extended fixations, they can control the fixation duration threshold to only place a mark when they look at a region for a lengthy period of time (see Figure 3, left). Furthermore, if the physical relationship between those places is

[5] http://collablab.northwestern.edu/iris/

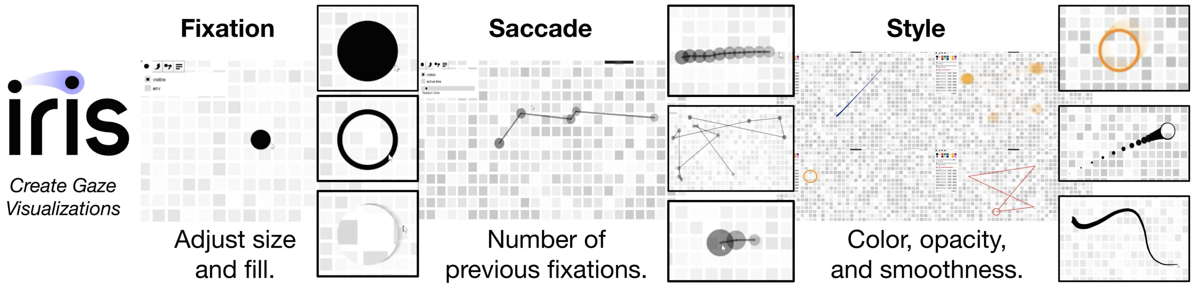

Figure 1: Gaze visualization design features in Iris.

not important to illustrate, users can remove the connecting line to simply display points. The representation of more recent extended fixations can be made larger to provide a cue that captures previous conversation points. Additionally, if they want to display a cursor to show where they are currently looking to support referential communication, that can be shown as well.

The zoom lens is another gaze representation feature in `Iris` that can single out and magnify what a user is looking at without obscuring the larger visual space. This feature is well suited to viewing content that contains details which could go unnoticed by some users. For example, in Figure 3 (middle) the visualization uses a 2.0x zoom lens to highlight an important area of an x-ray image. This emphasizes the focal point without obscuring the rest of the image. As another example, a short duration, low opacity heat map can provide a subtle real time indicator of attention. The visualization does no artificial smoothing of the gaze data, but the low opacity of each segment in the heat map provides a stable yet highly responsive representation. This is very well suited to a dynamic environment (see Figure 3 right).

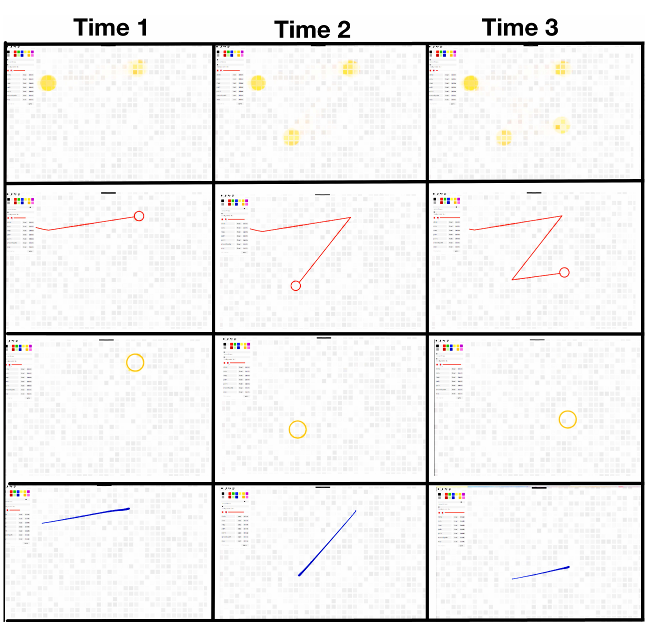

Figure 2: Example of different gaze visualizations played on the same gaze recording.

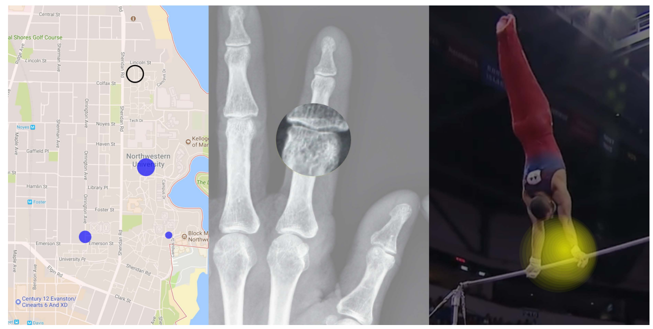

Figure 3: Examples of Iris design features.

4 USER STUDY

To investigate the potential application of our system, we performed a user study. Participants were calibrated at the beginning of the study and given a demonstration of the `Iris` system where a researcher provided instructions on how to interact with the editing features. Once comfortable with the system, participants were informed that they would be designing gaze visualizations for specific tasks and they could ask questions at any time. Using the think aloud protocol, participants were asked to describe their design process and thinking to the two researchers present.

During the study, participants were asked to design gaze visualizations for six different tasks that varied across important dimensions. The first three tasks were static images including: a word document, a map, and an x-ray image. The last three tasks were dynamic videos including: a moving traffic scene, a video of a live fish tank, and a recording of a gymnastics routine. Participants were asked to create visualizations that they would want someone else to see if they were collaborating. For example, editing a document together, giving directions, scoring a gymnastics routine, etc. The study lasted 30 minutes with 5 minutes for instruction and 25 minutes for design and discussion. The participant's screen and audio was recorded. Eight students at a Midwestern university participated in the study (four male and four female), and they gave written consent and received $20 for their participation.

4.1 Findings

There were two primary actions performed by participants to create gaze visualizations, (1) adjusting color and opacity to illustrate meaning and (2) using gaze trails to signal meaningful connections

Figure 4: Examples of visualizations created by users.

in the visual content. The following describes how these features of gaze visualizations were used by participants and can be explored by researchers to create contextually relevant gaze visualizations.

4.1.1 Use of Color and Opacity to Fit the Context. Color is a simple feature of a gaze visualization that is not often manipulated in other systems. In our study, participants frequently changed the color and opacity of the gaze visualization to best suit the context of the task. For example, in the writing prompt, participants described using opacity to better signal role.

> "If I'm in the professor role I would probably use something less opaque to show that I'm like not taking control so much as attempting to help... now if I was the student I would probably have something that is more solid" -P2

Incorporating meaningful color choices can help illustrate important information for the task. For example, participants mentioned if they were co-editing the document they would leverage collaboration norms such as using red to call attention to an area or yellow to signal editing (see Figure 4 top left).

> "I think the colors are helpful if you want to switch modes, you can kind of be more in an editing mode with yellow because it's like highlighting" -P4

4.1.2 Use of Gaze Trails to Illustrate Meaningful Connections. Visualizing previous fixation points can illustrate meaningful connections and show how someone looked at the visual space over time. However, the accumulation of past information can also be distracting. For example, when visualizing a teacher's gaze information in an online lecture, it was found that a 5 second trail of gaze information was too distracting and participants preferred to see only 2 seconds of past gaze information [Sharma et al. 2016]. However, this study revealed that the amount of desired information may depend heavily on the task. For example, in static tasks when the sequence is important, we see that participants want to illustrate an extended trail of gaze information (Figure 4 top right).

> "I don't want the trail to disappear I want it to stay visible on the map because presumably if I'm showing someone directions for the first time they are not going to remember it" - P5

However, in dynamic tasks such as driving, participants felt that displaying past information could distract from the demands of the task, especially since unexpected moving elements easily draw the eye away involuntarily. Further, with the scene continuously changing, the trail of information would be highlighting different objects over time, which may not be relevant (Figure 4 bottom left).

> "it would be helpful to have a single pinpoint of what is most critical because having too much at the same time with those things being there in real life in a task that requires fast thinking would be too much" - P1

While in a majority of the dynamic tasks participants chose not to illustrate a gaze trail, some participants did attempt to use it to aid recognition. For example, when identifying a fish in an exhibit, participants claimed that seeing the previous fixation information helped provide information about the movement trajectory (see Figure 4 bottom right, trajectory illustrated in yellow).

5 DISCUSSION

In this work we present `Iris`, a tool for designing contextually relevant gaze visualizations. Our user study reveals important stylistic features of gaze visualizations that can be tailored to specific contexts or roles. The most common included color changes, opacity, and smoothness, which can provide subtle cues to reveal users intentions or fit into a context of use.

`Iris` allows users to manipulate the design of gaze visualizations to represent the wide range of information they want to communicate, which cannot be achieved with the current tooling. Researchers and designers can use `Iris` to make simple stylistic changes to convey more information in gaze visualizations or explore more complex representations. For example, a decision regarding the desired amount of previous gaze information displayed can depend on the task features (e.g. static and dynamic tasks).

The use of remote eye trackers and unrestrained users also reduces the quality of the eye tracking data [Holmqvist et al. 2012; Niehorster et al. 2017]. However, we see that participants compensate and used the features in `Iris` to create designs that were robust to the limitations of the technology. For example, participants used larger fixation pointers to account for imprecision and increased smoothness to reduce the impact of noise.

Finally, it is important to note that we recruited novices for our user study who are not familiar with eye tracking or gaze visualizations. While this allowed us to understand a perspective towards gaze visualization design that is not biased by current techniques, we would like to acknowledge that not all the features of `Iris` were explored in the user study.

In conclusion, we presented `Iris`, an open source project and tool that makes manipulating eye movement data easy and can be utilized to create effective gaze visualizations that are directly informed by the context of use. Future devices will likely include eye tracking capabilities that can be leveraged for novel interaction techniques. By improving access to tools for designing gaze visualizations, we can improve our understanding of eye movement behavior and explore new ways to represent gaze information.

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