Visualizing Eye Gaze Sequences

Project Proposal

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1 Project Description

Eye trackers are increasingly present in academic research and commercial applications [1]. Researchers in human-computer interaction use eye tracking to study the usability of computer interfaces, as it can provide data that describe user behaviour and reveal usability problems that traditional methods might have missed [8]. It has also been used in various medical exams, e.g., for detecting schizophrenia [5], and in developmental psychology to study the perceptual and cognitive abilities of children [4].

Analyzing eye tracking data involves examining a set of quantitative metrics, including fixation count, saccade amplitude, pupil size, etc. While statistical analysis is suitable for generating these metrics, visualization techniques can reveal spatial-temporal patterns and trends in the data that can then be verified through statistical testing [1]. Thus, the tasks performed on eye tracking visualizations include understanding overall distribution of fixations and identifying sequential patterns of user's eye movement. To draw conclusions about the behaviours of a group of users requires comparing the patterns and finding common ones among users.

Eye tracking datasets are often large in volume: the size of a dataset from an HCI experiment is often on the order of hundreds of thousands of fixations [1]. For spatial-temporal analyses, the necessary attributes in the input data are the coordinates of the fixations and timestamps. To display in-context visualizations, the visual content provided to the users during the experiment is needed. Regions of the visual content can be defined as areas of interest (AOI), and they usually follow the semantic information of the content.

2 Personal Expertise

I have been working with eye-tracking data in my research project on adaptive visualization for a year. The goal of the project is to infer a user's cognitive abilities and the difficulties of the presented visualization tasks from user's gaze behaviour. I had attempted to achieve this goal using machine learning approaches with AOI-based gaze sequence features, but the resulting classification accuracies were not as desired.

3 Proposed Solution

The eye tracking dataset has the properties of **spatial**, node-link **network**, and **time-series** data. Each fixation is situated at a spatial location and contains the attribute of fixation duration. Two fixations are linked together by a saccade, which is a fast movement of the eye. When fixations are aggregated into AOIs, AOI transitions can form a type of network that allows directional links and multiple links between two AOIs.

Reduction is a suitable strategy for dealing with these large volume datasets, as the visual clutter resulted from displaying all fixations and saccades would impede the analysis. The two subdivisions of reduction strategies are filtering and aggregation [7].

Various algorithms for aggregating fixations and scan paths have been developed (e.g., [2]). Considering the scope of this project, the **aggregation** used will be in the form of grouping fixations by predefined AOI or dynamically defined regions.

The dataset can be reduced through **filtering** by the following criteria:

- filter by individual user, task, and/or trial in the experiment so that only the fixations and scan paths of the selected user/task/trial are displayed;
- filter by time intervals within the trials, e.g., only show the fixations occurred during the first 3 seconds of each trial;
- highlight fixations in the selected region, where the region can be a predefined AOI or a dynamically defined region;
- highlight sequences of fixation following a defined pattern, e.g., all transitions between AOI 1 to AOI 2.

To coordinate the spatial and temporal information, the system contains **multiple views**.

- The **timeline** view acts as a control for filtering by time interval, and temporal information, such as AOI duration, can be overlaid on the timeline. If multiple trials are selected, a list of timelines are arranged vertically and aligned on the left (i.e., the start time).
- The **trial** view shows the list of trials grouped by either user or task and acts as a filter control with multiple selection.
- The **eye-gaze** view displays the spatial information of fixations and scan paths on top of the visual content presented to the users in the experiment. This view allows selection of regions to facilitate filtering fixations by region and filtering sequences by a series of regions.

Once a filtering is initiated in one view, the other views are updated. For example, when the user selects a region in the eye-gaze view, fixations outside the region are faded out, the timeline highlights the timestamps at which these fixations occur, and the trial view shows the frequencies of the occurrence of the selected fixations in each trial.

The filtering in the eye-gaze view is visualized through **dynamic layers**. The bottom layer in the view is the visual content presented to the experiment participants, and this layer allows for in-context analysis.

4 Scenario of Use

Jim is a HCI researcher who just conducted an experiment and collected eye tracking data of the participants.

1. First, he exports the data from the eye tracker and transformed it to the format supported by the system.
2. Then, once he loads the data into the system, an overview of all the fixation is displayed, the trial view is populated with trials that are grouped by users and by tasks, and if AOIs are defined, the timeline view is color-coded by AOI durations.

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Figure 1: Mockup design of selecting a sequence of regions. The timeline component is based on [6].

3. Next, Jim selects individual trials one-by-one to examine the data in details; the eye-gaze view and the timeline view update accordingly on demand.
4. Then, Jim wants to focus on the first 10 seconds into each trial, so he adjusted the slider on the timeline to filter out fixations that occurred after 10 seconds.
5. Once he observes a region in which many fixations concentrates, he selects it, and fixations that fall outside the region are faded out.
6. Now, he is presented with the option of showing the neighbours of the highlighted fixations, and he chooses to show neighbours that are one saccades away. He quickly finds a common trend of a series of three steps, i.e., there is a common neighbourhood that leads into the selected region and a common neighbourhood that follows from the selected region.
7. Jim wants to see how often this specific sequence occurs in the rest of the dataset, so he builds a custom sequence by selecting three regions consecutively (Figure 1). As a result, the trial view shows the frequencies of this sequence, and the timeline views show the time intervals at which this sequence occur.
8. In the trial view, he notices that this particular sequence occur frequently for half of the users, rarely occur for the other half, so he decides to look more closely at this sequence and investigate the statistical significance of this difference.

5 Proposed Implementation

I plan to implement this system as a web application and build mainly with the D3.js library. I will also reply on the Crossfilter JavaScript library to support the coordinated views. The supported input data format will be JSON initially.

6 Milestones

M	Target	Tasks
1	Nov. 7	Finalize detailed design
		Build the eye-gaze view showing fixations and saccades
2	Nov. 14	Build the trial view
		Support filter eye-gaze view by trials
3	Nov. 21	Build timeline view
		Support filter eye-gaze view by time intervals
4	Nov. 28	Build selection by region
5	Dec. 5	Build highlighting neighbours
		Build selection by sequence of regions
6	Dec. 12	Prepare final presentation and reports

7 Previous Work

Traditional visualization approaches via scan path and heat map suffer from visual clutter and the lack of temporal information, respectively [9]. The temporal information, in terms of the sequence of users eye movement, can often reveal insights such as the efficiency of the arrangement of elements in the interface and user's strategies when processing the visual information [8].

There has been an increasing number of eye-tracking visualizations developed in recent years [1], and some components of the proposed visualization system use designs implemented in previous systems. For example, the timeline view is similar to the design of the "scarf plots" in the ISeeCube system [6], and the style of the scan path follows the coding strategy designed by Goldberg and Helfman [3]. Blascheck et al. surveyed the field and found that many of the systems lack the support for interactive analysis [1]. They classified these systems according to a set of categories; the proposed system is both point- and AOI-based and facilitates interactive spatial-temporal analysis with multiple users. There is no existing system that falls into this set of categories.

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