What Are They Doing? : Real-time Analysis of Eye-Tracking Data

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Abstract

We demonstrate the feasibility of real-time analysis of eye-tracking data captured from multiple people concurrently using an interactive visualization. We leverage the Data of Interest (DOI) approach, in which gaze coordinates are related to a visualization's content as it is rendered, to output data objects that users are interested in at any given time. We show in a controlled user study that subjects could interpret real-time DOI streaming from multiple users concurrently, to determine in real time what tasks those users were doing. We briefly discuss potential applications of our methods in teaching and in developing gaze-contingent visualizations.

1 Introduction

Eye-trackers tell us where on the computer screen users are looking, and have been a valuable diagnostic tool in disciplines such as psychology, cognitive science, human-computer interaction, and visualization research [4]. Traditional eye-tracking workflows (e.g., point-based analysis, area of interest (AOI) analysis [2]), rely on gaze coordinates collected in conjunction with rendered visual stimuli, and require a significant amount of human annotation to relate gazes to the semantic meaning of the stimuli [1]. This meant that eye-tracking analyses were generally performed laboriously, offline.

A new breed of accessible eye-trackers (e.g., around 150) opens up the possibility of equipping regular workstations with eye-trackers, enabling novel eye-tracking applications. One is the monitoring of eye-tracking data in real-time. For example, it is conceivable that classroom computers could be equipped with eye-trackers, and visual learning environments instrumented to capture what students are looking at. Instructors could use such data in real time to identify students who struggle and provide proactive help. Similarly, if regular workstations featured eye-trackers, visual analytics systems could be instrumented to monitor user's data interests and make recommendations. Finally, commercial add-placement systems could benefit from integrating real-time eye-tracking information with manual interactions to improve their recommendations.

Such real-time analyses are facilitated by Alam et al.'s recent proposal of data of interest (DOI) eye-tracking data interpretation [1], which involves instrumenting the rendering code of a visualization to automatically relate gazes to the visual content displayed on the screen. The DOI method outputs in real-time what data-objects users are looking at during a visual exploration. Moreover, because this data is the same as the one underlying the instrumented visualization, it has direct semantic meaning, is tied to the tasks users are doing, and can be useful even if separated from the visual stimulus from which it was collected.

We hypothesized that an analyst could look at such data in real-time, as it is streamed from multiple users of a visualization concurrently, to infer what those users were doing. We validated this hypothesis through a user study.

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2 Evaluation

General procedure: We used Alam et al.'s approach to instrument a PivotPaths visualization [3] of movie data from the Internet Movie DataBase (IMDB). We used the visualization to collect DOI from 9 subjects, solving a range of movie related tasks. We created a visualization that could show DOI data coming from multiple users concurrently in real-time and invited 10 subjects to analyze the collected DOI. Five of these subjects analyzed the data in a simulated real-time scenario: we streamed the previously collected DOI through our visualization gradually, as if it was captured from multiple users right then. The other five subjects analyzed the same DOI data but in an offline-scenario: subjects were shown all data from the beginning and could rewind. We asked subjects to identify what tasks their monitored users were doing, and compared their answers to the real task descriptions.

PivotPaths visualization: Our instrumented visualization system allowed its users to search movies, actors, or directors, and created diagrams of data most closely related to the search, using a layout exemplified in Figure 1. The system's rendering code was instrumented using Alam et al.'s approach to capture movies, actors, directors, or genres that users viewed.

Collecting DOI: We collected DOI from 9 graduate and undergraduate students solving movie related tasks in the system described above. We used a light weight 60Hz EyeX Tobii eye-tracker. Users were paid $10 for their effort. After training sessions in which we taught users how to interact with the PivotPaths visualization, we asked users to complete the tasks below. We will refer to these tasks as "data collection tasks" (DC).

<u>DC_Task1:</u> Given two movie titles, "Raiders of the lost ark" and "Indiana Jones and the last Crusade", find two actors, two genres, and one director they have in common.

<u>DC_Task2:</u> Given a director name, James Cameron, and a list of three actors, Arnold Schwarzenegger, Linda Hamilton, and Sigourney Weaver, rank the actors in terms of their collaboration with the director.

<u>DC_Task3:</u> Given three movie titles, "Catch me if you can", "E.T.: The extra-terrestrial", and "Captain Phillips", recommend a fourth movie.

Visualizing DOI data: Our visualization of streaming DOI is exemplified in Figure 2. Given the current time t in a user's DOI stream, we identified the ten data objects that user viewed most in the recent $t-90$ second time span. We created heatmap representations which list those ten objects vertically, show time horizontally in 1 second increments, and color cells based to indicate interest in objects at a particular time. Viewed data objects were ordered vertically and scaled based on the amount of interest the user expressed in them during the considered time window. We stacked heatmaps on top of each other, one for each individual user, and note that heatmaps changed gradually as new data streamed in.

Interpreting DOI in real-time, a user study: We invited 10 subjects to participate in a data analysis (DA) study in which we assessed their ability to interpret the collected DOI. We gave our subjects an incomplete definition of the tasks that DC users had to do, used the DOI visualization to show them data from five users, and asked them to infer the missing details in the task descriptions. We also randomized the order in which each of our DC users completed their three tasks, and asked our subjects to indicate when the monitored users started new tasks and what these were. Specifically, subjects solved the following four tasks:

DA_Task1: For each featured user, indicate when they are starting a new task and what that task is.

DA_Task2: Knowing the movie title of DC_Task 1, identify the common elements that DC users would have found (two actors, two genres, one director).

DA_Task3: Knowing the director name in DC_Task2, identify the the three actors named in the task.

DA_Task4: Knowing the three movies involved in DC_Task3, identify the movie that users would have found.

Five of our analysts saw all their users' data at once, replicating an offline analysis. For the remaining five we simulated an online scenario by streaming data gradually. We hypothesized that offline analysts will provide more accurate results because of their ability to analyze the entire data at once at a more leisurely pace. Our design was intended to capture the difference. In terms of protocol, we gave subjects an introduction to eye-tracking, described the procedure used in the DC stage, and gave them their task descriptions. We then allowed them to become familiar with the data involved in their tasks by browsing imdb.org. This was followed by a training session in which subjects were shown the DOI visualization, and viewed a few minutes worth of data from half of our DC users. Finally, we conducted the actual study using the data collected from our remaining DC users.

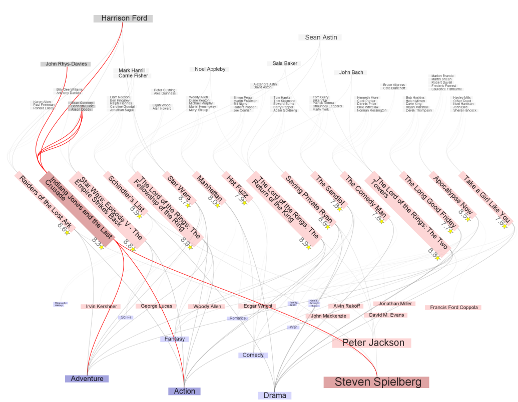

Figure 1: PivotPaths visualization of IMDB data. Movies are displayed in the center of the screen, actors at the top, and directors and genres share the bottom space. Actors, directors, and genres associated to movies are connected through curves. Users can highlight objects and their connected neighbors by hovering over them.

3 Results and Discussion

We computed correctness of our DA subjects in identifying the missing information by using the Sorensen-Dice coefficient [5], and show these values in Figure 3. We found that offline analysts were just slightly more accurate than real-time analysts, and that both groups faired well. Offline users were significantly more accurate solving DA_Task 4 (i.e., identifying the recommended movie) since the two groups differed in how they approached this task. Offline users located their users' recommendation tasks, then picked one of the last movies users viewed, since they were more likely to be an end-answer; real-time users quickly identified when a recommendation task started and rushed to pick movies that their users considered early on. The real-time analysts also tended to be less accurate in detecting transitions between tasks. Finally, offline users seemed more observant of the actual heatmap values, while real-time users reported that they focused mainly on the sorted labels on the sides.

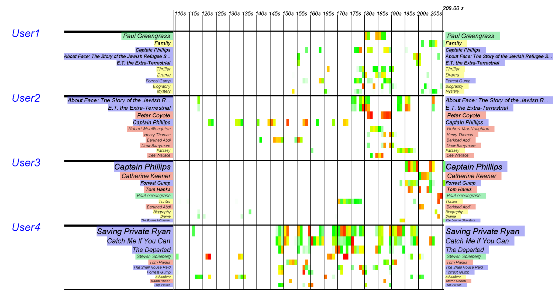

Figure 2: Visualization of DOI streaming from multiple users concurrently. For each user, ten most viewed objects in the last 90 seconds are listed vertically, ordered and scaled by the amount of interest the user showed in them. Time advances horizontally (most recent moment on the right), and color indicates the degree of interest in an object at every 1 second interval.

While our preliminary results are promising, we acknowledge that our analysts monitored only a few concurrent users. Even so, we provide a first account of how DOI eye-tracking can be used to enable real-time tracking of users' visual interests, and provide a stepping stone for applications described in Section 1. Moreover, we believe more complex visualizations that borrow encoding principles and functionality from time-line and event monitoring applications, could allow analysts to track many users at once. This is supported by one of our approach's main advantages: the ability to track users' eye-tracking data without having to look at the visual stimuli they viewed; this allows us to stack compact visualizations of multiple users' data, and pose complex computational queries.

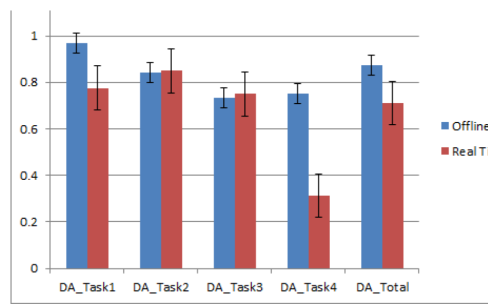

Figure 3: Barchart diagram showing the correctness of offline users vs real-time users.

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