Data of Interest (DOI)-Based Analysis of Eye-Tracker Data for Interactive Visualizations

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Abstract

Interest in eye-tracking technology has proliferated in the visualization community in the last decade [2]. Currently, gaze information is analyzed in the image space that gaze coordinates were recorded in, generally with the help of overlays such as heatmaps or scanpaths, or with the help of manually defined areas of interest (AOI). Such analyses require significant manual input and are not feasible for studies involving many subjects, long sessions, and heavily interactive visual stimuli. We propose *Data of interest (DOI)-based analysis*: a new way of analyzing data provided by eye-tracking devices. Unlike existing point-based and AOI analyses, which focus on the coordinates and areas of the stimuli that users viewed, DOI-based analysis leverages the known structure of an evaluated visualization to detect in real time which individual elements of the visualization are being viewed, and relates those to the base-data from which the visualization was built. We show that DOI-based analysis can be particularly useful for analyzing the use of highly interactive visualizations.

1 Introduction

Eye-tracking devices provide data about users' gaze position on the screen. Using eye-tracking as a diagnostic tool, scientists from disciplines such as psychology, cognitive science, or human-computer interaction are able to derive and test hypotheses about users' visual, attentional and cognitive processes [4]. Eye-tracking technology is also becoming an integral part of information visualization research. Currently, approaches of analyzing eye-tracking data, point-based analysis and areas of interest (AOI) analysis [2], require significant manual input from experimenters and are thus time-consuming for long experimental sessions on interactive stimuli. We propose a novel way of analyzing eye-tracking data which we call data of interest (DOI)-based analysis. DOI-based analysis focuses on the analysis of eye-tracking data in the data space that visualizations were created from, rather than the image space of already rendered stimuli. Instead of manually defining static AOIs on the stimuli, we can use the known structure of the visualization at render time to match gaze coordinates directly to visualization and data elements. DOI-based analysis removes the overhead of manually defining AOIs, making it feasible to analyze highly interactive visualizations over longer periods of times, provided these visualizations can be instrumented. The data produced by DOI-based analyses is highly granular, and because it is grounded in the often static data underlying the visualization, it can be easily aggregated over multiple users. We demonstrate the feasibility and benefits of DOI-based analysis by exploring data collected from a small user study involving a highly interactive visualization.

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2 Related Work

Eye-tracking technology is a convenient method to analyze user behavior or attention processes in fields such as psychology, cognitive science, human-computer interaction, and data visualization [4]. Given this broad applicability, diverse approaches to analyze eye-tracking data have been proposed, several of which stem from the visualization and visual analytics domains [1]. Such techniques permit the researchers to analyze eye-tracking data not only quantitatively but also qualitatively. Blascheck et al. [2] compiled various existing visualization techniques applicable to eye-tracking data. All such methods involve significant manual input from experimenters, whether in the form of coding images and videos or defining AOIs. The challenge of analyzing eye-tracking data thus arises when analyzing many users during long analysis sessions using highly dynamic stimuli. The work presented here differs by shifting the paradigm of eye-tracking analysis from rendered stimuli to visualization and data space. Through our methodology, our work comes close to that of Papenmaier and Huff who proposed DynAOI, a tool that relates gazes directly to 3D content [6]. By targeting data-rich information visualizations, our work differs in terms of implementation challenges and opportunities.

3 Methods

We build on initial results by Okoe et al. [5] who show that gaze can be reliably translated into visualization objects that users are looking at. While Okoe et al. used this to create gaze-responsive visualizations, we apply the idea to evaluative analysis of gaze data. To evaluate the feasibility and potential of the technique, we set forth to perform an eye-tracking user study on a highly interactive visualization, the PivotPaths visualization proposed by Dork et al. for multifaceted data [3]. We created a basic PivotPaths implementation which we connected to the popular internet movie database (IMDB). As in the original PivotPaths, users could search for movies or names of people in the movie industry (actor, actress or director). When users selected a person, a PivotPaths diagram was generated containing top rated movies, genres and names of other people related to those movies. Users were able to pan and zoom in the visualization. As in the original design, selecting a person in a shown diagram causes the visualization to transition to a new view centered on the selected person. A PivotPaths diagram for Leonardo Dicaprio is shown in Figure 1.

We instrumented this visualization with viewed-object detection techniques similar to those proposed by Okoe et al. [5]. Specifically, a viewing score is maintained for each visible visualization object. An object's score increases whenever user gazes land in the vicinity of that object and otherwise decays gradually over a short time period. This score is directly translated into likelihood that the user is viewing an object at a given time. We note that when gaze-coordinates land sufficiently close to multiple objects all these objects can have no-zero likelihood of being observed at the same. This should be interpreted as an uncertainty as to what the user is really looking at.

For the analysis, we have generated simple heatmaps to look at the data at different time frames (Figure 2 (a) and (b)). Thus, heatmaps can have more or less columns, depending on the gran-

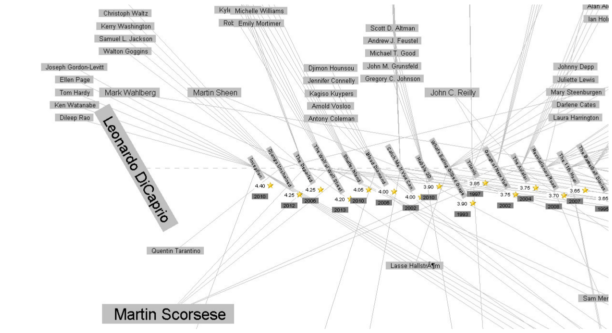

Figure 1: PivotPaths diagram for Leonardo Dicaprio.

ularities of time frame. The color represents the intensity of the attention of the user during the user study. The heatmap could also be sorted based on which elements where viewed most or which elements were viewed earliest in the study.

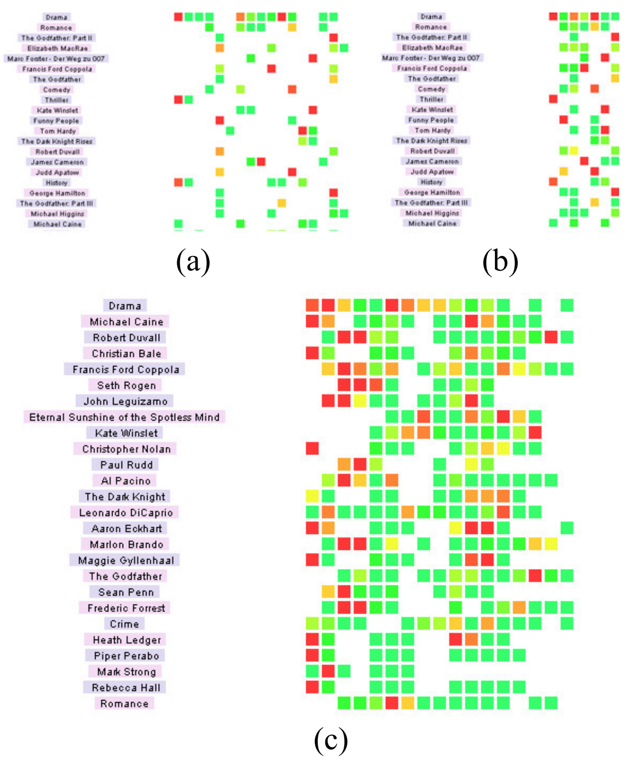

Figure 2: Generated heatmap for a single user with time granularity of (a) 2 minutes and (b) 5 minutes. (c) Heatmap generated from user study data with time granularity of 2 minutes. Due to space constraints, only first 25 most viewed data elements of 300 are shown.

4 Evaluation

We collected DOI data for the PivotPaths visualization from 8 graduate computer scientists using a SMI RED-120Hz eye-tracker. Each session lasted approximately 45 minutes, of which 35 minutes represented actual interaction time and 10 minutes was allotted at the beginning of the study for training and eye-tracker calibration. Each participant was awarded ten dollars for their time.

Users were asked to perform four simple movie related tasks. First, given two movie names they had to find four common items (director, genre, actor or actress) between them. Second, they had to rank collaborations between given directors and actors in terms of number of movies they worked together on. Third, given three movies they had to recommend a fourth one based on self-discovered measure of similarity. Fourth, they had to perform basic information retrieval such as identifying top-rated movies or most worked with actors for a given person.

Figure 2 (c) shows a heatmap of DOI aggregated over all eight participants. The figure demonstrates our ability to easily aggregate data over all users. Together with Figure 2 (a) and (b), it also demonstrates the validity of the approach. Rather than being random, the collected data is correlated with the tasks users had to do and patterns in the data. For instance, the heatmap reveals that The Dark Knight movie was viewed in conjunction with people involved in its production (e.g., Christopher Nolan, Christian Bale, Heath Ledger, Maggie Gyllenhaal etc.). This is unsurprising since these elements were instrumental to solving two of the tasks. A similar story is told by the temporal correlation between Francis Ford Coppola, his favorite genres (Drama, Crime), The Godfather, and actors involved in The Godfather series. The temporal ordering shows that users first investigated The Dark Knight movie and then The Godfather which corresponds to the first two tasks they were given. The heatmap also shows that movie genres were among the most viewed data elements, which is also not surprising given that they are common for all movies that a user would have searched for. Moreover, the heatmap also shows that genres were viewed predominantly during first and third tasks when users had to propose recommendations, which is also an intuitive finding.

5 Conclusion

The contribution of this work is introducing DOI-based analysis, a novel way of analyzing eye-tracking data in visualization and data space. We demonstrated the feasibility and validity of the approach by collecting approximately 300 minutes of eye-tracking data from subjects using a highly interactive visualization and showing that the collected data is correlated to the tasks subjects were asked to do and patterns in the data. Moreover, we were able gain such insights in a matter of minutes, both for individual and aggregated data, without coding video stimuli or manually defining AOIs. This would not have been possible with existing techniques and demonstrated the potential of the approach for analyzing data visualizations that can be instrumented. While additional work is needed on integrating interaction events and stimulus snapshots into the analysis or exploring how existing AOI visualization methods can be extended to this type of data, our work lays the foundation of eye-tracking studies in data space. This approach can lead to eye-tracking based analyses that go beyond exploring how people look at pictures and instead focus on how people use data to solve problems.

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