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Exploring Eye Movements with Node-Link Graph Layouts

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Abstract. Analyzing eye movement data is challenging, in particular, if visualizations are used that directly show the eye movements on the stimulus. However, it is important to identify visual scanning strategies in context of the semantics of the displayed stimulus. In this paper, we investigate the idea of providing node-link diagrams using multiple graph layouts in which each is directly linked to the visual stimulus, but represented in a separate view. Typically, a single graph layout provides specific information and has certain benefits. Hence, we propose to compare several common and easy to implement graph layout algorithms in multiple-coordinated views to extract different scanning strategies of participants. The nodes of each node-link diagram hereby model areas of interest while the weighted links denote the transitions between the areas of interest. Additionally, we illustrate the usefulness of our approach by applying it to a formerly conducted eye tracking study focusing on route finding tasks in public transportation maps.

1. Introduction

Data collected during eye tracking studies can be analyzed using qualitative or quantitative methods. A qualitative evaluation of eye movement data using visualizations can lead to insights about the scanning strategies of participants. This more visual form of analysis relies on the perceptual abilities of an analyst (Blascheck et al., 2017). However, visual analytics systems developed for eye movement data (Kurzhals et al., 2017) do not only support algorithmic or statistical analyses of the data, but also a combined analysis with interactive visualization techniques.

Graph visualizations, especially, node-link diagrams, are a powerful concept to reflect the principle of connectedness between groups of objects. When applying graph visualization to eye tracking, nodes can model areas of interest (AOIs) while links can visually encode the transitions between the AOIs. In addition, a node-link diagram can be linked to the stimulus to convey contextual information that is otherwise lost. This can be achieved by overlaying the stimulus with a node-link diagram or by showing several of the graph layouts side-by-side using multiple-coordinated views. In addition, interaction is crucial for an analysis and an analyst should be able to define the spatial or temporal aggregation level of the eye movement data when generating node-link diagrams.

Our experience is that one graph layout is not sufficient for an analysis, because an analyst typically wants to solve different tasks with a node-link diagram. Therefore, each task requires to inspect the eye movement data from different perspectives. Multiple perspectives on the same data can be gained by using different graph layout algorithms. For example, if an analyst is interested in symmetries between related AOIs, a force-directed layout (Fruchterman and Reingold, 1991) can be the right choice. If the flow of visual attention is to be reflected, a hierarchical layout (Sugiyama et al., 1981) is better suited. Finally, a radial layout (Six and Tollis, 2006) is useful if all AOIs are treated equal. Therefore, in this paper, we present a multiple-coordinated views (Roberts, 2004) approach to analyze and compare several graph layouts for eye movement data. An analyst can change the spatial and temporal granularity, investigate the different graph layouts in context of the stimulus using brushing-and-linking (Becker and Cleveland, 1987), and analyze properties of the nodes.

2. Concept

Analyzing eye movement data requires to support multiple analysis tasks (Kurzhals et al., 2017). Node-link diagrams offer such a multi-analysis, because different graph layout algorithms can be generated to show different aspects of the eye movement data. In the following, we discuss previous work and our design choices. We further provide information about the graph structure used and last present our prototype.

2.1. Previous Work

Many eye tracking visualizations have been developed (Blascheck et al., 2017) with attention maps (Bojko, 2009) and gaze plots (Noton and Stark, 1971a and 1971b) being the most popular ones. However, attention maps aggregate the data temporally and gaze plots suffer from overplotting.

In the survey by Blascheck et al. (2017), AOI-based methods, and especially graph-based ones, provide an option to compare and relate interesting regions on a stimulus. Most of these techniques either represent graphs statically (Blascheck et al., 2017, Section 6.3) or dynamically Burch et al. (2014). However, in both cases the layout of the graph is fixed and cannot be changed during an analysis.

In many cases eye tracking visualizations are directly placed on top of the stimulus to better support an analyst and provide contextual information. This approach can be problematic for two reasons: (1) the stimulus is occluded and important semantical information can be lost and (2) the visual representatives are fixed to the corresponding spatial positions on the stimulus, therefore, gaining a different perspective on the data is hard. In this paper, we reflect on different graph layouts to compare node-link diagrams of eye movement data applying either a force-directed (Fruchterman and Reingold, 1991), hierarchical (Sugiyama et al., 1981), or radial (Six and Tollis, 2006) layout.

2.2. Design Choices

We primarily base our design decisions on previous work. We found that most of the approaches in the literature (Blascheck et al., 2017) suffer from stimulus occlusion or layout restrictions, as is the case, for example, with attention maps or gaze plots. Therefore, we first transform the eye movement data into AOIs and transitions between them are modeled as weighted and directed relations. This data can be represented as a node-link diagram providing an inherent relational structure. However, there exist different layouts, all having benefits and limitations. Hence, we decided to analyze the eye movement data using a combination of layouts in a multiple-coordinated views approach. This allows us to benefit from the strengths of each graph layout.

To explore eye movement data using node-link diagrams, our approach currently offers three different graph layout algorithms which can be compared with each other. Currently, the approach provides a force-directed, a hierarchical, and a radial layout. These layouts are the most prominent ones and are easy to implement, serving as a starting point for further extensions of our approach.

2.3. Generation of the Graph Visualizations

We first aggregate the eye movement data spatially and temporally. This preprocessing generates a graph $G = (V, E)$ (see also Burch et al., 2014). The vertices V are a set of AOIs, aggregating the fixations. The edges $E = V \times V$ are the corresponding weighted transitions between AOIs. The generated weighted graph can be represented using the different graph layouts.

Our approach offers three state-of-the-art graph layout algorithms. First, a node-link diagram using the force-directed layout generated with the Fruchterman-Reingold algorithm (Fruchterman and Reingold, 1991). This layout is especially useful to depict groups in the graph and allows to find paths, subgraphs, and symmetries between related groups (Pohl et al., 2009). Second, we provide a graph layout based on the Sugiyama algorithm (Sugiyama et al., 1981) to generate a hierarchical layout, depicting the flow of visual attention. Last, a radial layout (Six and Tollis, 2006) is used, which treats all AOIs equal. For this layout, we first compute a linear order of the nodes, to show clusters and reduce visual clutter (Rosenholtz et al., 2005).

2.4. Prototype

We implemented a prototype using Java and the JavaFX framework. An analyst can first choose the grid size, which is used to generate the graph. All fixations are aggregated based on the grid and saved in a linked list. Each element in the list contains information about the x- and y-coordinate, the timestamp, the fixation duration, and the predecessor as well as the successor of each node.

The prototype depicted in Figure 1 is a multiple-coordinated view approach with five views. On the left, Figure 1 A shows a list of stimuli and participants currently loaded. On the right, four multiple-coordinated views can be loaded: In Figure 1 B the stimulus with the grid and the chosen grid size is shown, in which the generated graph is overlaid on the stimulus. Additionally, an analyst can choose to show the graph independent of the stimulus. Furthermore, the graph is depicted using the force-directed (Figure 1 C), the hierarchical (Figure 1 D), and the radial layout (Figure 1 E).

An analyst can interact with the graphs shown in each view. A zoom and pan option is available to resize and move the stimulus and graph. Furthermore, a brushing-and-linking-based approach can be used to select individual nodes in the graph. When selecting a node, an analyst can choose a specific color for this node and all other views are updated and highlight the node with the selected color. Additionally, all successors and predecessors of a node can be highlighted as well. This requires that a node has to be selected and highlighted first, then the successors and predecessors are highlighted in the same color. Additional information about the node is shown as well: the average x- and y-coordinate of the fixation node; the average timestamp of the fixation node; the average duration of the fixation node; and the number of fixations aggregated into the fixation node.

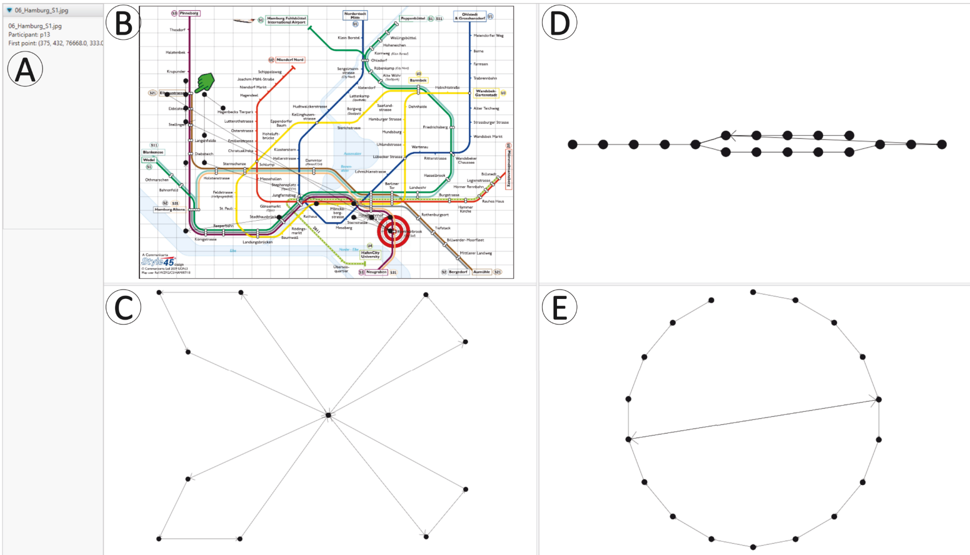

Figure 1. In this example, A) depicts the list of participants and stimuli loaded. B) shows an example stimulus with a 20×20 grid and the generated graph. The same fixation data shown using a C) a force-directed, D) hierarchical, and E) a radial layout.

3. Application Example

In the following, we analyze data from an eye tracking study (Netzel et al., 2017). In the study, participants had to find a path from a source to a destination station using different public transportation maps. For detailed information, we refer to the original study by Netzel et al. (2017). In our example, we analyze one stimulus depicting a metro map from Hamburg, Germany. We describe some insights we were able to gain using the different layouts with a grid size of 20 rows and 20 columns.

For the force-directed layout, we found some graphs which have a center element leading to a graph with multiple subgroups. In the hierarchical layout, we found that most of the generated graphs have many hierarchy levels and each level only contains one or two nodes. For the radial layout, we retrieved a number of graphs that only have a few nodes, which were visited multiple times. In some cases, we can observe that when participants revisit a node, they perform a cross-checking to confirm their answer for the task.

With the chosen grid size (20 rows and 20 columns), some of the graphs are cluttered, because the fixations are not aggregated enough. In these cases using a grid size of 15 columns and 15 rows or even less is helpful to reduce the number of nodes. However, to compare participants, choosing the same grid size is important.

4. Conclusion

In this paper, we presented an approach using node-link diagrams of eye movement data. Our approach allows to apply different levels of granularity to aggregate fixations and generate node-link diagrams. We use three different graph layout algorithms, namely force-directed, hierarchical, and radial layout, to represent the node-link diagrams. These different layouts allowed us to compare data from an eye tracking study analyzing public transportation maps.

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