

Investigating Crossing Perception in 3D Graph Visualisation

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Abstract

Human perception and understanding of graph drawings is influenced by a variety of impact factors for which quality measures such as the number of crossings are used as a proxy indicator. For the more and more common stereoscopic 3D (S3D) graph visualisations, evidence is required to better understand graph perception and its relation to quality measures. We investigate the perception of crossing configurations in S3D graph visualisations and present the results of a study.

2012 ACM Subject Classification Human-centered computing → Empirical studies in visualization; Human-centered computing → Virtual reality; Human-centered computing → Graph drawings; Human-centered computing → Visual analytics

Keywords and phrases Graph Perception, Stereoscopic 3D Graph Visualisation, Crossing Configurations

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1 Motivation

The investigation of impact factors for graph perception is important to evaluate and improve quality measures and drawing algorithms as well as to better understand human graph perception. The number of edge crossings in a 2D graph drawing has long been a main quality measure for drawing evaluation and is still regularly investigated and reported. Their impact is however dependent on further factors such as graph size or crossing angle [6, 3, 9]. The use of stereoscopic 3D graph visualisations has gained attraction over the last years, and results from several studies indicate that they can improve analysis efficiency for a range of analysis scenarios [4, 1, 2, 7, 10]. The importance and effect of impact factors for perception might differ from the classical 2D setting, e.g. due to the influence of depth cues and eye depth focus. While edge crossings can also occur in 3D, there are edge configurations in space that are not crossings but might be perceived as such from a specific viewpoint.



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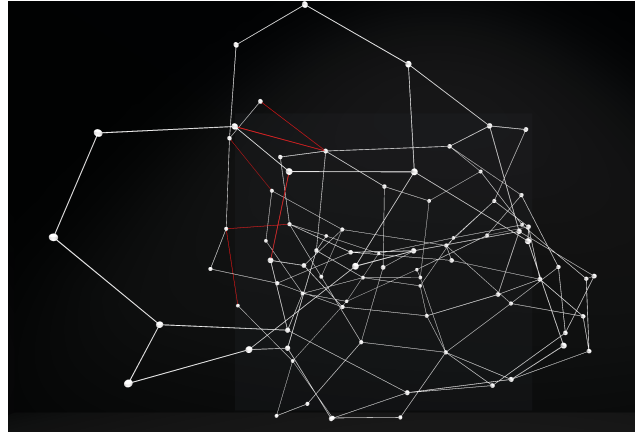
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Such configurations create crossings when projected on the corresponding 2D image plane and could impact readability similar to 2D crossings. To indicate that most of such edge configurations are not edge crossings in 3D per se, but could be perceived as such, we call them ‘*projective edge crossing configurations*’, or ‘PECC’ in short. The additional depth aspect and the subsequent impact factor of edge distance in space might further influence the importance of those configurations for readability, and also change the influence of aspects such as the perceived crossing angle. We investigate the impact of such factors in an empirical study and report on findings of difference between major factor categories.



■ **Figure 1** Graph representation for our study in VR, edges highlighted for memorisation task.

2 Study Design and Setup

As an initial step to investigate the effect of PECCs on graph perception in S3D, we investigate their influence on task performance. As controlled impact factors that serve as independent variables for our study, we add the depth distance of the edges in 3D space at the projected crossing points (IV3) to the established criteria of number of crossings (IV1) and crossing angle (IV2) (which we measure in the projection as an indicator of the perceived number and angles). The study participants were asked to perform three established tasks on 3D graph visualisations in VR: shortest path (SP), common neighbours (CN), and memorisation (ME). We recorded the completion time and accuracy, and the participants were told to perform tasks as accurately and as quickly as they could, while the pace was controlled by the participant. We chose a VR environment for the study, as we could fully control the appearance of the environment and graphs to minimise distraction. The participants remained seated during the study, wearing a head-movement tracking VR HMD (Meta Quest 2), with graph visualisations shown centred in front of their viewpoint, see Figure 1. Except for small head movements, there is no interaction that allows the viewer to change the visual representation of the graphs, in order to avoid changes in the impact factor values. We implemented a Unity application based on the VR graph analysis framework GAV-VR [5].

For the stimuli, we restricted our study to a single graph generator model, the Newman-Watts-Strogatz random graph model, which allows to create graphs with a good combination of local clustering and shortest path lengths as often found in practice [8]. For the layout we decided to use a standard spring-model layout, which provides a reasonable readability for the tasks, as tested by us before the study. In order to test clearly separable conditions for our independent variables, the stimuli were categorised into factor levels as having either low

or high number of (projection) crossings - up to 2 (level L) and at least one per task-related edge on average (level H), crossing angles - below 30° (level L) and above 60° (level H), and crossing point distances - as fraction of full graph representation depth (up to 0.1 level L and above 0.3 level H). We calculate these variables task-related: Instead of measuring them across the whole graph, we investigate PECCs that are involving task-relevant edges, i.e. (shortest) path edges for SP and ME and edges adjacent to the selected nodes for CN. This results in eight conditions, encoded as XYZ in the following, where X indicates the level for IV1 (H for high, L for low), Y the level of the average IV2, and Z the level of the average IV3. We recruited 28 participants (12 male, 16 female) at our university, aged 19-36 years (avg. 24.46). Thirteen of them reported prior VR experience, and seven reported previous graph analysis experience. All participants reported normal or corrected-to-normal vision. We performed a within-subjects experiment and counter-balanced task and condition order.

3 Results

We assumed that, in line with previous studies in 2D setups, it will be easier to perform the tasks with less crossings and larger angles, and in addition that larger edge distance would be the easier factor level, too. In summary, we have for accuracy significant differences between high and low PECC numbers (all tasks), but only for task SP between high and low angles and between high and low distances. For completion time (see Table 1), we recorded significantly shorter times for low PECC number combinations (LXX) across all tasks, shorter times for low angle combinations (XLX) for tasks SP and CN, and no significant differences for distance levels. We could see significant impact on both accuracy and completion time based on differences between pairs of conditions, but also between low and high levels of the number of PECC. Compared to known 2D results, we could observe similar effects for the number, but in contrast to 2D results no similar result for angles, which we deem an important find to be further investigated in future research. For depth impact, we established significant differences between high and low levels of PECC distance. Thus, we think that a deeper investigation of PECC impact factors should be a topic of future research to improve layout quality measures and algorithms for S3D.

■ **Table 1** Accuracy and mean RT across all tasks per condition, sorted by RT. Expected impact of count, angle, distance indicated based on our hypothesis. Highest and lowest values in bold.

CC	Count	Angle	Distance	Accuracy (%)	Mean RT (s)
HHH	Hard	Easy	Easy	50.0 %	21.3
HHL	Hard	Easy	Hard	42.9 %	20.7
HLL	Hard	Hard	Hard	53.6 %	19.0
HLH	Hard	Hard	Easy	65.5 %	17.1
LHL	Easy	Easy	Hard	73.8 %	15.4
LHH	Easy	Easy	Easy	79.8 %	15.1
LLL	Easy	Hard	Hard	76.2 %	12.7
LLH	Easy	Hard	Easy	82.1 %	12.5

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Perception of Edge Crossings in 3D

An Investigation of Projective Edge Crossing Configurations in Stereoscopic 3D

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The use of stereoscopic 3D (S3D) graph visualisations has gained attraction over the last years, and results from several studies indicate that they can improve analysis efficiency for a range of analysis scenarios [1,2,3,4]. The importance and effect of impact factors for graph perception, as covered by many established quality measures, might differ from the classical 2D setting. The impact of edge crossings has been considerably studied in 2D, but there are no similar investigations for S3D. We conducted a first study and report on our findings.

Perceived Edge Crossing Configurations: There are edge configurations in space that don't need to be crossings but might be perceived as such from a specific viewpoint. Such configurations create crossings when projected on the corresponding 2D image plane and could impact readability similar to (2D) crossings. We call them 'projective edge crossing configurations', or 'PECC' in short. Several factors might determine the impact of PECCs, in particular similar to the 2D case their number as well as the crossing angle (in the projection). Further factors are specific to the S3D scenario, such as the distance of the edges in space at the perceived crossing point.

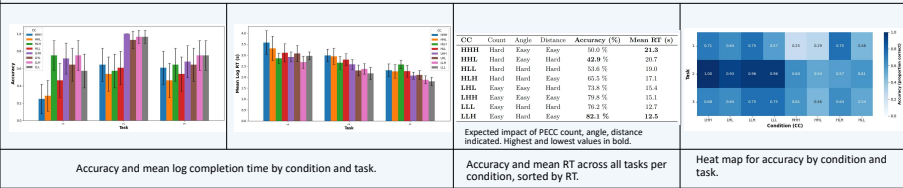
Aim: Investigate the impact of PECCs on task performance, using as independent variables PECC number, PECC crossing angle, and PECC crossing edge distance. For each independent variable we distinguish two levels, low (L) and high (H). This results in eight conditions, represented as XYZ in the following, where X indicates the level the number, Y the level of the average angle, and Z the level of the average distance of PECCs.

Tasks and Procedure: The study participants were asked to perform three established tasks on 3D graph visualisations in VR: shortest path (SP), common neighbours (CN), and memorisation (ME). Only PECCs that are directly related to task-relevant structures are taken into account, e.g. PECCs involving edges of the shortest path. The participants remained seated during the study, wearing a head-movement tracking VR HMD (Meta Quest 2), with graph visualisations shown centred in front of their viewpoint. Except for small head movements, there is no interaction that allows the viewer to change the visual representation of the graphs, in order to avoid changes in the conditions. PECC distance is measured as the ratio of the distance to the overall drawing depth.

		Task 1: Shortest path - given two highlighted nodes, find a shortest path between them and report its length (in number of edges). Left: Challenge stimulus with highlighted nodes Right: Solution path, with a high number of PECCs (on average at least one per edge), high average PECC angles (greater than 60°) and high average PECC depth distance (condition HHH)
		Task 2: Common neighbours - given two highlighted nodes, count their common neighbours and report their number. Left: Challenge stimulus with highlighted nodes Right: Common neighbours highlighted in green, with a high number of PECCs on edges adjacent to the red nodes, low average PECC angles (less than 30°) and low average PECC depth distance (condition HLL)
		Task 3: Memorisation - given a highlighted path, and a highlighted set of edges shown after a pause, decide the overlap and report the number of edges highlighted twice. Left: Memorisation stimulus with path highlighted, with low number of PECCs, high average PECC angles, and high average PECC depth distance (difficult to perceive in 2D printing) (condition LHH) Right: Challenge stimulus with single edges highlighted

(Note: The representation was slightly adjusted for better readability in a 2D print by changing the lighting.)

Results



Summary: Significant differences in accuracy between high and low PECC numbers (all tasks), but only for task SP between high and low angles and between high and low distances. For completion time, significantly shorter times for low PECC number combinations (LXX) across all tasks, significantly shorter times for low angle combinations (XLX) for tasks SP and CN, and no significant differences for distance levels. Significant impact on both accuracy and completion time based on differences between pairs of conditions, but also between low and high levels of the number of PECC. Compared to known 2D results, we could observe similar effects for the number, but in contrast to 2D results no similar result for angles, which we deem an important find to be further investigated in future research. For depth impact, we established significant differences between high and low levels of PECC depth.

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