A User Study on Curved Edges in Graph Visualisation

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1 Introduction

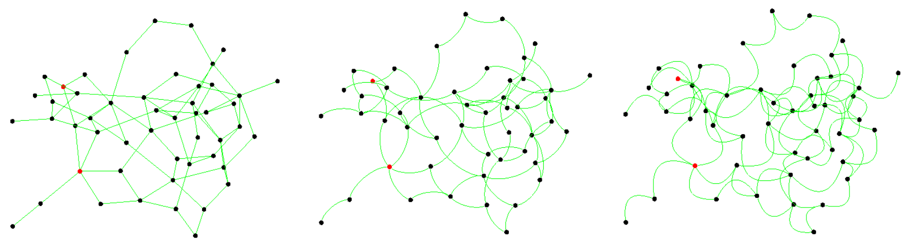
It seems that straight lines seldom occur in natural objects and that humans actually prefer curved lines [1]. Thus it may not seem surprising that in aesthetics, curved lines are often to be preferred over straight ones, as found for example in Hogarth's serpentine Line of Beauty [2]. More recently a number of "confluent drawings" [3] and "edge bundling" [4] methods have been proposed to reduce edge clutter by using curved edges. Inspired by the work of Mark Lombardi, there is also theoretical work [5] that uses curved edges to optimises *angular resolution*, i.e., keep the angles between adjacent edge uniform.

Many examples are available to demonstrate the results of graph visualization with curved edges. However, there has been little effort to empirically evaluate their effectiveness on common graph-related tasks. The only related experiment [6] we are aware of is a qualitative study comparing hierarchical edge bundling against node-link diagrams with five software developers. The data used were not general graphs (directed acyclic graphs) and the tasks were software engineering-specific. The results show that all participants strongly prefer hierarchical edge bundling to node-link diagrams.

In this paper we describe our experiment studying the impact of edge curvature on general graph readability. We wanted to avoid any confounding factors and limit the difference in visualization to edge curvature only. Therefore, we did not include edge bundling or confluent drawing methods, because they require special layout methods that can not be applied to straight-line graphs.

2 Experiment and Results

A total of twenty-eight subjects voluntarily participated in the study. They were from diverse social-economical background and included university students and staff (both academic and non-academic), and general public. The graphs used in the experiment were generated with the model proposed by Ware et al. [8]. The graphs have three sizes: 20, 50, and 100 nodes, and ten graphs were generated for each of the three sizes. The force-directed method [9] was then used to generate graph layout. After applying the layout algorithm, three visualizations were produced for each graph with straight, slightly curved, and heavily curved edges (Figure 1). A four-point Bezier curve was plotted for the slight curve, and three point Bezier curve was plotted for the heavy curve. The node positions were kept unchanged. A within-subject design is used. During the experiment, participants were asked to identify whether a path of length two existed between two nodes (i.e., path-finding task).



(a) Straight edge (b) Slightly curved edge (c) Heavily curved edge

Fig. 1. Examples of graph visualizations used in the experiment.

Hypothesis 1: Steeper arcs will be detrimental to performance as participants will have to follow a longer path between nodes.
Hypothesis 2: Task time will increase with the graph size.
Hypothesis 3: Participants would prefer straight edge for effectiveness, but slightly curved edges for aesthetics.

This study used two objective measures: time to answer (TIME) and the number of correct answers (CORRECT)) and two subjective measures: user preference on effectiveness (PREF-EFFECTIVE) and look (PREF-LOOK) of line type. Table 1 summarizes the pairwise comparisons using Tukey test for TIME and CORRECT. TIME: The ANOVA results showed that all the main

Table 1. Pairwise comparisons of two objective measures.

	Line Type			Number of Nodes		
	STL vs. SCL	STL vs. HCL	SCL vs. HCL	20 vs. 50	20 vs. 100	50 vs. 100
$Log_{10}(TIME)$	**	**	**	**	**	**
CORRECT		**	**		*	

* Significant at the $\alpha = 0.05$ level; ** Significant at the $\alpha = 0.01$ level

effects were statistically significant at the 0.01 significance level (line type (F(2, 54) = 16.31, $p < 0.01$) and number of nodes (F(2,54) = 26.64, $p < 0.01$). CORRECT: The main effect of line type was statistically significant at the 0.01 significance level (F(2,216) = 61.20, $p < 0.01$). The main effect of number of nodes was also significant at the 0.05 level (F(2,216) = 3.05, $p < 0.05$). PREF-EFFECTIVE and PREF-LOOK: For the two subjective measures, the Friedman test showed that there was a statistically significant difference among three line types (PREF-EFFECTIVE ($\chi_F^2 = 16.83$, $p < 0.01$; adjusted for ties) and PREF-LOOK ($\chi_F^2 = 16.83$, $p < 0.01$; adjusted for ties)). STL is the most preferable line type in both subjective measures.

3 Discussions

This study has found that edge curvature increase leads to longer task completion time, which is in agreement with our Hypothesis 1. It is also found that correct answer percentage decreases as curvature increases. These results indicate that using curved edges alone does not improve graph readability. The results also show that the time taken increases with the number of nodes for each curvature condition, which agrees with our Hypothesis 2. Participants preferred the aesthetics of straight lines to curved ones, and judged them to be more effective for the path finding task. This disagrees with Hypothesis 3 that curved lines would be preferred and the previously cited studies that show humans prefer curved contours. It is probable that any initial reaction is overridden by the requirements of our task. As a result, subjects prefer the look of straight lines when they find them easier to use for the task.

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