Perception of node-link diagrams: the effect of layout on the perception of graph properties

Elektra Kypridemou[1,2], Michele Zito[1], and Marco Bertamini[2]

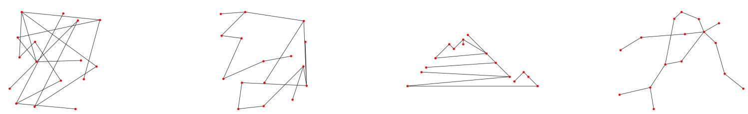
[1] Department of Computer Science
[2] Visual Perception Lab, Department of Psychological Sciences
University of Liverpool, Liverpool, United Kingdom
{e.kypridemou,michele,marcob}@liverpool.ac.uk

Abstract. The way we choose to draw the networks on the plane (layout) is found to be important for the readability of networks by humans. In this study, we examine how different layouts affect our perception of specific properties of small networks of 16 nodes each. We compare a simple grid layout to the planar and force-directed layouts, which are some of the most well-established layout algorithms. We also introduce an alternative improved grid layout, which optimizes the outcome layout in terms of specific aesthetics. When people had to decide whether a network is a tree given a node-link diagram, the layout significantly affected their performance. The same pattern appeared for the detection of the connectedness property. However, when people had to detect two properties at a time, the layout didn't affect their performance. The results show that the layout we choose for representing a network is crucial for our perception of some of the network's basic properties. However, when people had to detect more than one property at a time, the chosen layout didn't seem to significantly affect their performance.

1 Introduction

Node-link diagrams are commonly used to visually represent entities (nodes) and their relationships (links), also known as networks. They are widely used to visualize and communicate linked data. There is a great amount of graph drawing algorithms that generate such visual representations of graphs (also called layouts). These algorithms usually aim to optimize some visual characteristics (or 'aesthetics') of the drawing, that are found to affect the readability of the graph [1, 2]. Previous empirical studies explored the perception of node-link diagrams in terms of their aesthetics, usability and readability [3]. The first study to investigate the effect of different layouts on the human perception of specific graph properties was published by Soni et al. [4]. They used graphs of order 100 for all the experiments, which resulted in stimuli that looked like clouds of lines and dots. Hence, their approach can not necessarily be generalised for the perception of other graph properties. Kypridemou et al. [5, 6] explored the perception of graph properties in much smaller graphs of 16 nodes.

In this study, we further extend the previous work of Kypridemou et al. on



(a) Grid (b) Grid_i (c) Planar (d) Spring

Fig. 1: The four layouts.

graphs of the same size (16 nodes), using some common properties (connectedness, tree), as well as a new property that is expressed as a combination of two other properties. We compare a simple grid layout with well known planar and spring layouts. We also introduce an alternative improved grid layout, which reduces the number of crossings while keeping most of the simplicity of the original grid layout. We use signal detection theory (SDT) [7] to analyse the d prime (d') and bias (c) dependent variables that will give us a better understanding of the sensitivity and the bias of participants' performance.

2 Method

The experiment consisted of three different tasks, which we call Treeness, Connectedness and Multi. For the Treeness task, participants had to detect whether the given graph was a tree or not. For the Connectedness task, participants had to decide whether the represented graph was connected or not. Finally, for the Multi task, participants had to decide whether the graph 'has at least one of the following features: a) a loop/cycle of length 3 *or* b) at least a node with degree higher than 4'.

All stimuli were drawings of planar simple graphs of 16 nodes each, which were visually represented as node-link diagrams using the following layouts: a random grid layout (Grid), an improved version of a grid layout (Grid_i), a planar layout (Planar), and a spring layout (Spring). Exemplar stimuli for each of the four layouts are provided in Figure 1. A more extensive description of the specific algorithms and procedures used for drawing each of the layouts can be found in [8]. The resulting 200 drawings of each task were depicted as node-link diagrams of red dots of fixed size and black lines of fixed thickness (Figure 1). Figure 2 shows the sequence events of a trial. In the study participated 16 participants (7 male, 9 female, 18 to 41 years old), with no prior knowledge on graphs.

3 Results and Discussion

The qualitative results about the specific strategies used in each task are described in [8]. The results of the SDT analysis are shown in Figures 3 and 4. For the treeness property, there was a significant main effect of layout on the sensitivity ($F(3, 45) = 32.81; p < 0.001$) and the bias ($F(3, 45) = 7.18; p < 0.001$)

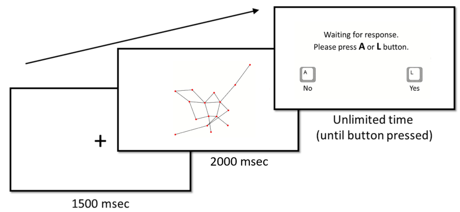
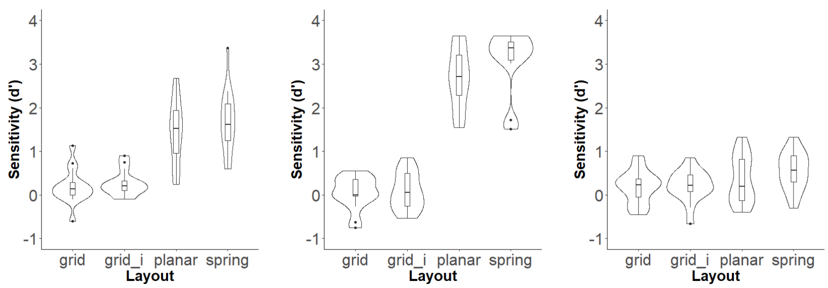
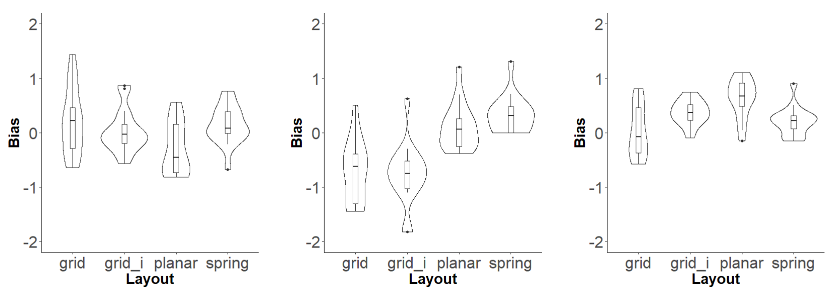


Fig. 2: Event sequence of one of the experiment's trials.



(a) Treeness (b) Connectedness (c) Multi

Fig. 3: Violin plots of sensitivity (d') per layout for each property.



(a) Treeness (b) Connectedness (c) Multi

Fig. 4: Violin plots of bias per layout for each property.

metrics. Similarly, for the connectedness task, the layout was found to have a significant main effect on the sensitivity ($F(3, 45) = 191.64; p < 0.001$) and the bias ($F(3, 45) = 55.62; p < 0.001$) metrics. For the multi task, the layout was not found to have any significant main effect on the performance for the sensitivity metric ($F(3, 45) = 2.32; p > 0.05$), but there was a significant main effect of the layout on the bias metric ($F(3, 45) = 14.42; p < 0.001$). Additional statistical analyses are described in [8].

The results on the treeness and the connectedness properties are consistent with the previous findings of Kypridemou et al. [5] on the same tasks on graphs of the same size. This indicates that the findings are generalised from comparison tasks to detection tasks. Furthermore, the SDT framework of this study provided more in-depth understanding of the ability of the participants to detect the signals on the stimuli. The two versions of the grid layouts biased the participants towards identifying non-connected graphs as connected. This bias is probably because these two layouts tend to draw the two connected components of the non-target graphs as overlapping shapes, which makes the graphs look as connected.

The Multi task revealed some new findings, extending the previous study. The results show that the layout we choose for representing a network is crucial for our perception of some of the network's basic properties. However, when the task becomes harder and people have to detect more than one property at a time, the chosen layout doesn't seem to significantly affect performance.

There is a large variety of other graph properties to be explored in future work. The results of such studies could lead to better understanding as per which layouts are most appropriate for visualizing graphs, when the aim is for humans to be able to detect specific graph properties. Looking towards this direction, graph visualization will not be discussed as a one-solution-fits-all approach, but will rather be a more customized solution per case, given the task at hand.

References

1. Bennett, C., Ryall, J., Spalteholz, L., Gooch, A.: The aesthetics of graph visualization. Computational aesthetics **2007**, 57–64 (2007)
2. Purchase, H.: Which aesthetic has the greatest effect on human understanding? In: International Symposium on Graph Drawing. pp. 248–261. Springer (1997)
3. Yoghourdjian, V., Archambault, D., Diehl, S., Dwyer, T., Klein, K., Purchase, H.C., Wu, H.Y.: Exploring the limits of complexity: A survey of empirical studies on graph visualisation. Visual Informatics **2**(4), 264–282 (2018)
4. Soni, U., Lu, Y., Hansen, B., Purchase, H.C., Kobourov, S., Maciejewski, R.: The perception of graph properties in graph layouts. In: Computer Graphics Forum. vol. 37, pp. 169–181. Wiley Online Library (2018)
5. Kypridemou, E., Zito, M., Bertamini, M.: The effect of graph layout on the perception of graph properties. EuroVis (Short Papers) pp. 1–5 (2020)
6. Kypridemou, E., Zito, M., Bertamini, M.: The effect of graph layout on the perception of graph density: An empirical study. EuroVis (Short Papers) (2022)
7. Stanislaw, H., Todorov, N.: Calculation of signal detection theory measures. Behavior research methods, instruments, & computers **31**(1), 137–149 (1999)
8. Kypridemou, E., Bertamini, M., Zito, M.: Perception of node-link diagrams: the effect of layout on the perception of graph properties (2022), https://osf.io/4b5k7