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# Improving multiple aesthetics produces better graph drawings ☆

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ABSTRACT

Many automatic graph drawing algorithms implement only one or two aesthetic criteria since most aesthetics conflict with each other. Empirical research has shown that although those algorithms are based on different aesthetics, drawings produced by them have comparable effectiveness.

The comparable effectiveness raises a question about the necessity of choosing one algorithm against another for drawing graphs when human performance is a main concern. In this paper, we argue that effectiveness can be improved when algorithms are designed by making compromises between aesthetics, rather than trying to satisfy one or two of them to the fullest. We therefore introduce a new algorithm: BIGANGLE. This algorithm produces drawings with multiple aesthetics being improved at the same time, compared to a classical spring algorithm. A user study comparing these two algorithms indicates that BIGANGLE induces a significantly better task performance and a lower cognitive load, therefore resulting in better graph drawings in terms of human cognitive efficiency.

Our study indicates that aesthetics should not be considered separately. Improving multiple aesthetics at the same time, even to small extents, will have a better chance to make resultant drawings more effective. Although this finding is based on a study of algorithms, it also applies in general graph visualization and evaluation.



## 1. Introduction

Graphs, defined as a set of vertices and a set of edges that connect the vertices, have been widely used to model network data for various purposes. Research in graph drawing concerns the problem of constructing geometric representations of graphs. That is to design an algorithm that takes a graph as an input and calculates the positions of vertices to optimize a set of pre-defined layout requirements. The final representations of graphs are usually in the form of so-called node-link diagrams.

According to Di Battista et al. [7], layout requirements used in algorithm design can be classified into three fundamental parameters of graph drawing: drawing conventions, aesthetics and constraints. Drawing conventions are normally common practices or requirements of real-life applications. For example, draw each edge as a straight line, or draw each edge as a chain of horizontal and vertical line segments. Constraints are rules that only apply to subsets of a graph or parts of a drawing, rather than the entire graph or drawing. For example, place a given vertex close to the center of a drawing, or place a subset of vertices close to each other. Aesthetics are a set of visual properties that algorithms are required to achieve in the final drawings, as much as possible, in order to improve readability. Examples of aesthetic criteria include the following:

- Minimum number of edge crossings.
- Maximum size of crossing angles.
- Uniform edge lengths.

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- Maximum angular resolution of vertices.
- Even distribution of vertices.

### 1.1. Two experiments of purchase

The past two decades have seen a fast growing body of research dedicated to designing algorithms to construct aesthetically pleasing drawings of graphs [7]. For excellent reviews on graph drawing algorithms, see [7,29]. While judgement of the quality of a drawing is subjective, it is generally believed that drawings that conform to the aesthetic criteria should be more effective in conveying the embedded information to the viewer. This belief is also supported by empirical work mostly done by Purchase. In particular, in her seminal work, Purchase and her colleagues [34] examined the effects of three aesthetics: crossings, bends and symmetry. For each aesthetic, the same graph was drawn three times with the value of the aesthetic in consideration being varied (see Fig. 1). Then the users were asked to perform the same graph reading tasks with the three drawings. The task performance was measured as the number of errors and they found that, for example, more errors were made when there were more crossings. In other words, increasing the number of crossings decreased the readability of graph drawings.

It is often tempting to optimize aesthetic criteria as many as possible in the same drawing in order to achieve the best possible readability. However, this can be practically difficult to achieve. Firstly, optimization of even a single aesthetic can sometimes be computationally difficult. For example, minimization of edge crossings is NP-complete [16]. As a result, a number of algorithms take a heuristic approach by which the aesthetic in consideration is not necessarily optimized in the resulting drawings. Secondly, most of the aesthetics are mutually exclusive; it is difficult, if not impossible, to implement all of the aesthetics *to the fullest* at the same time. For example, look at the two drawings shown in Fig. 2. If we want to draw the graph with maximum symmetries, then edge crossings are necessary (left). On the other hand, minimizing the number of crossings can only be achieved at the cost of symmetry (right). As a result, many automatic graph drawing algorithms aim to draw graphs satisfying one or two aesthetics [9].

Despite the fact that algorithms may be based on different aesthetic criteria, Purchase [32] has shown in another user study that these algorithms produce visualizations with similar levels of effectiveness. In this study, eight different algorithms were compared based on human performance. These algorithms were of a great variety in terms of aesthetic criteria that each of them aimed to satisfy. A single graph that had 17 vertices and 29 edges was drawn by the algorithms resulting in eight stimuli (two examples of the stimuli were shown in Fig. 3). The stimuli included drawings produced by force-directed algorithms with few edge crossings, planar grid drawings with many sloped edges, orthogonal grid drawings with minimum edge bends, drawings with even distribution of vertices and drawings with maximum symmetries. Fifty-five computer science students participated in

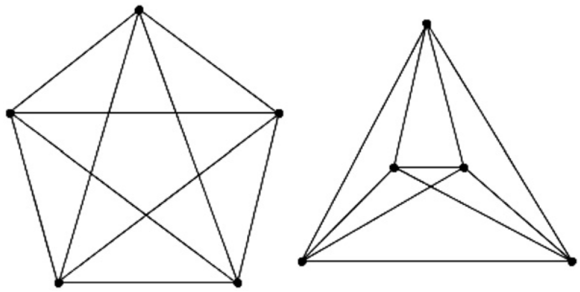

**Fig. 2.** Two drawings of the same graph. Left: maximum degree of symmetry; right: minimum number of crossings.

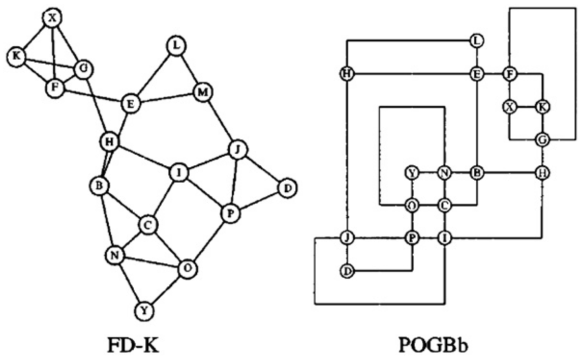


**Fig. 3.** Two examples of the drawings used in the study of Purchase [32].

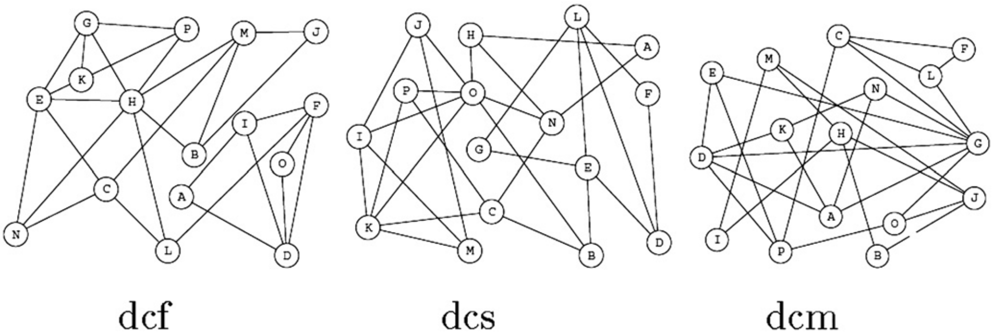


**Fig. 1.** Three crossing drawings of a graph with varied numbers of crossings [34].

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