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Techniques for Edge Stratification of Complex Graph Drawings ☆, ☆☆, ☆☆☆

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ABSTRACT

We propose an approach that allows a user (e.g., an analyst) to explore a layout produced by any graph drawing algorithm, in order to reduce the visual complexity and clarify its presentation. Our approach is based on *stratifying* the drawing into *layers* with desired properties; to this aim, heuristics are presented. The produced layers can be explored and combined by the user to gradually acquire details. We present a user study to test the effectiveness of our approach. Furthermore, we performed an experimental analysis on popular force-directed graph drawing algorithms, in order to evaluate what is the algorithm that produces the smallest number of layers and if there is any correlation between the number of crossings and the number of layers of a graph layout. The proposed approach is useful to explore graph layouts, as confirmed by the presented user study. Furthermore, interesting considerations arise from the experimental evaluation, in particular, our results suggest that the number of layers of a graph layout may represent a reliable measure of its visual complexity. The algorithms presented in this paper can be effectively applied to graph layouts with a few hundreds of edges and vertices. For larger drawings that contain lots of crossings, the time complexity of our algorithms grows quadratically in the number of edges and more efficient techniques need to be devised. The proposed approach takes as input a layout produced by any graph drawing algorithm, therefore it can be applied in a variety of application domains. Several research directions can be explored to extend our framework and to devise new visualization paradigms to effectively present stratified drawings.

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1. Introduction

Graph drawing algorithms are used in many applications to visualize networked information. Among them, force-directed algorithms are the most popular and are widely adopted to compute drawings in which vertices are represented as small circles and edges are drawn as straight-line segments. Of course, the chosen algorithm is of great importance in creating a readable visualization. However, when the graph is complex (large or locally dense) a high number of edge crossings are unavoidable;

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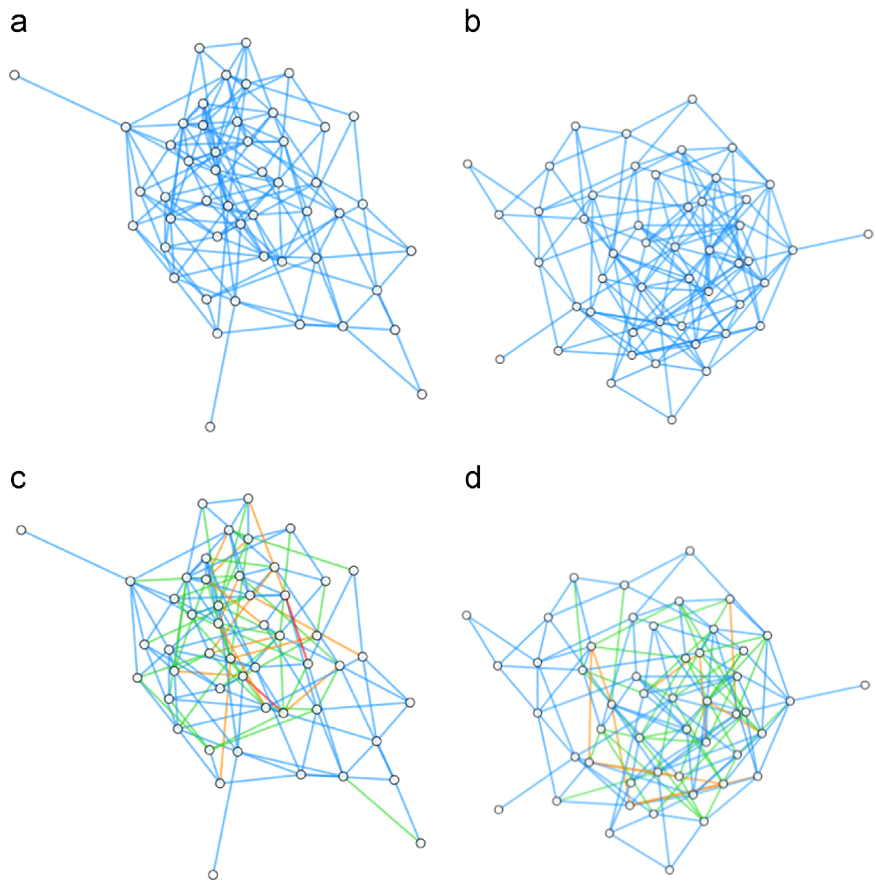

Fig. 1. (a, b) Drawings of the same graph computed by two different force-directed algorithms. (c, d) The same drawings in (a, b) stratified with layers having crossing angles of at least $\pi/4$; layers are conveyed with different edge colors. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

this is the case, for example, of most small world and scale-free graphs (see, e.g., [4,19,45]). It is well known that a high number of edge crossings seriously affect the drawing readability [40,41], and make it hard to perform detailed tasks based on visual inspection. These tasks include finding the shortest path between two given vertices, finding the vertices that are adjacent to both, or even determining the degree of a vertex.

In this paper we propose a new approach to support the user in the visual inspection of complex drawings. Namely, given a drawing Γ of a graph $G(V,E)$, we aim at partitioning the set of edges E into subsets $E_1, E_2, \ldots, E_h$, such that the subdrawing $\Gamma_i \subseteq \Gamma$ of each subgraph $G_i(V, E_i)$ guarantees some desired readability property (in each subdrawing, the vertices remain fixed in their original positions as determined in Γ). For example, a user could prefer to see Γ_i without any edge crossing, i.e., as planar, or so that any two crossing edges form a sufficiently large angle.

We say that Γ is *stratified* into a set of *layers* Γ_i, each containing all the vertices of Γ (in their original positions) but only a portion of the edge set. The user can then interact with this edge stratification by exploring one layer at a time, or by arbitrarily combining multiple layers into a single view. The edges of each layer are assigned the same color, and different colors are used for the edges of different layers. The main advantage of this approach is that users can get multiple readable views of different portions of the drawing, with the possibility of simplifying the total amount of information, thus allowing them to gradually acquire details by exploring or combining layers. On the negative side, from the cognitive point of view, the user has to face the difficulty of making sense of distributed information. To deal with this difficulty in practical terms, it is crucial to minimize the number of layers required to stratify the drawing so that the desired readability property is guaranteed for each layer. The main contribution of this paper is as follows:

- We define an edge stratification model and the related optimization problems. Then, we give a general framework to solve these problems for several desired readability properties of the layers, and we describe heuristics within this framework (Section 3).
- We present the results of a user study aimed at understanding the effectiveness of the proposed approach for executing tasks based on visual inspection (Section 4). These results highlight the usefulness of edge stratification, especially for some of these tasks and for some specific readability properties of the layers.

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