A Review on Quality Assessment Metrics for Edge Bundling Techniques

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Abstract

Edge-bundling techniques used in graph drawing simplify the graph structure and thereby offers an image easier to comprehend the structure for the human. The article reports metrics that were either used to quantitatively assess the edge-bundling results and/or was employed as the objective functions by the bundling algorithms. The study was conducted by reviewing 56 edge-bundling papers mainly published in VIS, EuroVIS, PacificVIS, and TVCG. Metrics for clutter reduction measure amount of ink usage, moving distances and the lengths of the control points, and curvature factor. Faithfulness is another type of measure that grasps loss of information in the bundled and therefore simplified image. The report compares and argues the advantage and disadvantage of the proposal.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Graph drawings; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

Since the proposal of force-based Hierarchical Edge Bundling (HEB) technique was proposed, edge bundling research has expanded over the decade (Fig. 1) [3]. The success of bundling techniques calls for assessment of their effectiveness in reduction of visual clutter [2], visual simplification [2], improved readability [10], and loss of structural information [4, 12].

This review focuses on the past use of quantitative metrics of the edge bundling techniques for undirected, unweighted graphs. There is a recent trend to expand the use of edge bundling techniques to graphs with rich edge semantics that incorporates the orientation, (possibly multivariate) weights, and temporality, but they are not covered in this report.

Among 56 edge-bundling papers, we collected ten quantitative metrics used as the objective function of the edge bundling process and/or to assess the effectiveness of the techniques [1, 2, 4–9, 11, 12].

The contribution of the paper is as follows. The quantitative evaluation metrics and objective functions being used in edge bundling are classified and compared. The article also addresses the inherent problems with the current metrics and suggests future research directions.

2 Metrics

Currently proposed quantitative metrics can be classified into two: measures of *clutter reduction* and *faithfulness*.

2.1 Metrics for Visual Clutter

Measures of visual clutter are used to compare visual clutter found in the unbundled and bundled graph drawing images.[1] The most

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[1]The term "readable" is commonly used to describe less-cluttered result. To avoid misleading in presence of "faithfulness", we use "visual clutter".

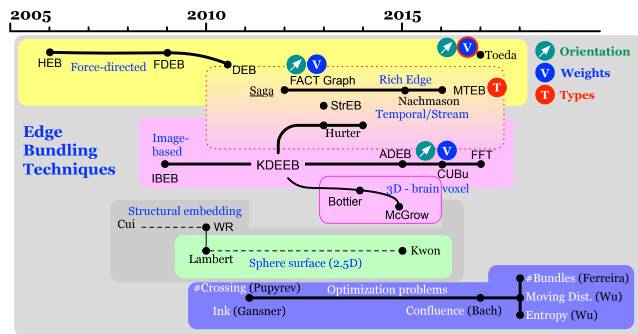

Figure 1: Illustration of the past edge bundling research

used measure is by *ink usage* for drawing graphs.

More common approach is *counting painted pixels*. As argued in [3], many more edges in comparison to the number of vertices is the source of visual clutter and merging them is an important goal of edge bundling. As effective edge merging is expected to reduce the ink usage, ink use is a conveniently employed. Another implicit purpose of ink usage is restraint from over winding bundled curves because such stretched curves consume more ink.

In [2], Gansner and others proposed a technique to bundle polyline segments. They accumulated the total sums of polyline segments to estimate the ink usage. A similar quantification approach has been taken by Pypyrev in *Swarm-based edge bundling*, or SwBEB, [7] and *mean edge length difference* or MELD by Saga [9]. An issue with this approach is twofold. First, because the quantified value is a summation of length, it is dependent on the resolution of the image. Another issue is that this measurement can only be applied to bundling methods that employ polyline segment bundling.

A more common ink-usage measurement approach is by counting painted pixels. Polisciuc and others propose swarm-based edge bundling technique ([6], SwBEB) that employ ink reduction as the objective function for their evolutionary computing. Saga's *mean occupation area* index (or MOA) enumerates grid cells that bundled edges pass [9]. A benefit of this approach is its simpleness. We can easily count and compare painted pixels of the unbundled and bundled images without restricting the bundling methods. A concern might be its dependence on image resolution and computational complexity of measurement. The latter issue prevents pixel-based ink measure from being used as an objective function of edge bundling.

Another class of visual clutter measurement takes account of distortion resulting from the bundling process. In addition to a simple ink-reduction index, Polisciuc and others experimented with a normalized ink-reduction by *edge curvature*, which comes from differential geometry [6]. Wu and others measure the distortion by the accumulation of the *total move of the control points*.

Similar methods were incorporated by Wu and others (reduced ink usage/overall distortion in [11]), and Saga proposes to measure *mean edge length difference* (MELD in [9]).

2.2 Metrics for Bundling Faithfulness

Nguyen and others studied the problem of types of misguiding results generated from the use of edge bundling techniques and proposed a framework of evaluation such issues [4, 5]. *Information faithfulness* consults the number of different graphs producing the same image. A fully information-faithful layout algorithm should be injective. It is a measure of information ambiguity introduced by the graph drawing and edge bundling methods. They suggest that an information theoretic approach to measure the loss of information faithful.

Wu and others defined *information-theoretic entropy* that quantifies ambiguity resulting from untraceable edges [12]. The proposed entropy compares visible adjacency of the unbundled and bundled node-link diagrams. A difficulty in calculation of this metrics is imitation of human recognition of connected pairs of nodes from edge bundled visualization.

The second type of bundling faithfulness discussed in [4,5] is *task faithfulness*. The concept of task faithfulness demands that a task that can be carried out by examination of the graph topology should also be equally accomplished well by looking at its visualization. A technical difficulty with computation of their faithfulness quantity is precise *reading* of connections among nodes. Their exemplification of task faithfulness scheme for edge bundling is a *stress* function that effectively is a square sum of edge compatibility and *Flétche distance* between curves. This definition is problematic because the definition relies on differences between incomparable metrics (compatibility and distance). The edge bundling survey suggests more suitable distance metrics such as *Hausdorff distance* and *path-to-skeleton distance* [3].

The last type of bundling faithfulness is *change faithfulness*. Its goal is to measure robustness of the visualization results from small changes in the original topology. Though interesting, no activity has conducted research on change faithfulness, yet.

Ferreira and others proposed a geometrically-based optimization framework for edge bundling [1]. Three different edge bundling strategies were formulated by giving different objective functions (*fitness functions*) based on the proposed framework: *angle-based edge bundling problem*, *compatibility-based edge bundling problem*, and *general-based edge bundling problem*. As the aim of the framework is to cluster the set of edges into disjoint sets of bundled edges, the fitness-based quantification cannot be applied to other edge bundling methods.

3 Summary and Future Direction

The report has reviewed various metrics served to globally optimize the edge bundling process and/or used to assess the quality of edge bundling methods. Metrics for reduced visual clutters measure improved simplicity. As they do not deal with human factors, such as misguiding human in reading the structure of the bundled graph, this type of measure alone is not adequate.

Another type of metrics deals with higher-level cognitive impact on human reader and hence seems more important. The metrics that fall in this kind measures information-loss, task-based, { spacial / semantic / connectivity / importance } compatibility.

We have found two styles of metrics: one style such as ink reduction takes unbundled and bundled images and produces the improvement as the result. Another style evaluates the bundled image according to the topology of the graph. Information-theoretic framework is one such example [12].

Some metrics are tightly coupled with the edge bundling algorithms and are not targeted for other algorithms.

We would like to address a few future directions. First, quantitative metrics are most useful when they measure performance of different bundling algorithms. Some measures described in this article are objective functions of the algorithms and depend on their specific features, and therefore suitable for this purpose. Beside comparison between algorithms, another use of the metric is to compare datasets by success in bundling. This is important to investigate the cause of the dataset that prevents bundling from generating more comprehensible image.

Quoting the success of CUBu and FFTEB, Lhuillier and others believe that "the scalability problem of path bundling has been sufficiently addressed, so that bundling can approach 'big data' sets". A remaining challenge is to compute the quantitative bundling measure of large datasets that can be efficiently bundled with recent technology.

Finally, it is important to assess the appropriateness of quantitative measures against task-based analysis. In this context, it is important to concern about different quality measures, most importantly understanding the difference between measures for clutter reduction and faithfulness.

We would like to address the above mentioned issues and find a quantitative metrics that are independent of edge bundling technique, dataset, and display resolution.

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