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Quantitative Evaluation for Edge Bundling Based on Structural Aesthetics

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Abstract

This study proposes a method to evaluate the efficiency of edge bundling. Edge bundling is important to improve visual clutter of edge visualization. However, the evaluation of edge bundling is based only on qualitative evaluations, and the evaluation cost is expensive. Therefore, this paper proposes three measurement strategies to evaluate edge bundling, namely, the edge lengths before and after edge bundling, occupation area, and edge density.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Line and curve generation,H.5.2 [Computer Graphics]: User Interface (D.2.2, H.1.2, I.3.6)—Evaluation/methodology

1. Introduction

Network visualization is one of the visualization methods that can express data and the relationships between data. Network visualization is based on graphical representation in mathematics. Hence, a network consists of vertices and edges, which also exhibit attributes. The vertex set is V, the edge set is E, and a network G is presented as $G = G(V,E)$.

Several methods can be used to visualize networks [HMM00]. Edge bundling has drawn recent attention as a novel approach to improve visual clutter. This method enables observers to recognize the main stream of edges through bundle edges in accordance with certain standards. For example, several methods based on the hierarchical structure of nodes [HvW09], parallel coordinates [ZYQ*08], mechanical models [TE10], spring force-based approach [HvW09] have been proposed.

These edge bundling methods are considered useful in certain cases. However, the efficiency of each method is difficult to compare. Time (e.g., calculation time and complexity), comprehension (such as readability), and presentation (e.g., expression, representation, and visual encoding) are generally considered in evaluation. Time can be evaluated logically and calculatedly by a computer, but comprehension and presentation need to be qualitatively evaluated by a questionnaire and interview.

Structural aesthetics influences comprehension. Some typical aesthetic rules include minimizing the number of bends in edges, minimizing the total area of a drawing, and minimizing the total length of edges and so on [WGK10]. The aesthetics in edge bundling follows several rules. The first rule is to minimize changes in the length before and after bundling. Large changes in bundling, that is, bundling that is too strong, result in loss of the direction of edges and loss of the vertices connected by the bundled edges. The second rule is the area occupied by edges. This rule is related to minimizing the total area of the drawing. The third rule is edge density. Density focuses on kernel-based edge bundling, and after edges are bundled, many edges are concentrated in a specific area.

Therefore, this study proposes a new evaluation strategy for edge bundling by using three rules on the basis of edge lengths before and after edge bundling, area occupation, and edge density. Overall, this research will help develop an evaluation method to conduct studies on edge bundling without qualitative measurement.

1.1. Contribution

The contributions of this research are that this evaluation method is first trial in the world, and that conducting studies on edge bundling is not necessary to evaluate qualitative measurement.

2. Measurement of Edge Bundling

2.1. Difference between Edge Lengths

The first measurement is based on length. In edge bundling, less change in edge lengths is assumed to indicate better edge bundling results. Edge bundling changes the lengths of the edges and attempts to bundle them. However, over-bundling often loses the meaning of the original network. Therefore, the above assumption can be considered reasonable. From this assumption, an evaluation measure called Mean Edge Length Difference (MELD) is proposed, as shown in Equation (1) and Figure 1.

$$MELD = \frac{1}{n} \sum_{e \in E} |L'(e) - L(e)| \tag{1}$$

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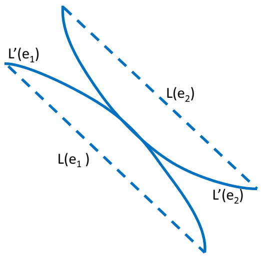

Figure 1: *Mean Edge Length Difference (MELD).*

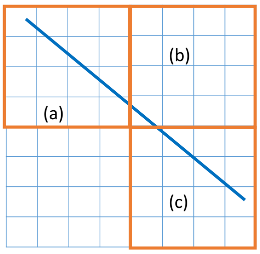

Figure 2: *Mean Occupation Area (MOA) (Unit Size: 4).*

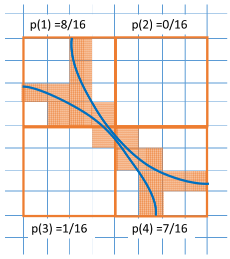

Figure 3: *Edge Density Distribution (EDD) (Unit Size: 4, Unit Areas:4).*

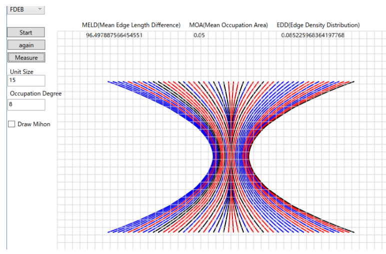

Figure 4: *Evaluation Measurement Demo.*

where n is the number of edges, $L(e)$ is the length of edge e after edge bundling, and $L(e)$ is the original length of e.

2.2. Area Occupation

The second measurement is based on occupation area in screen. Generally, the area of edges before edge bundling is larger than that after bundling. Given this phenomenon, a better bundling can compress the area occupied by the edges.

To calculate the area occupied by the edges, two parameters are used, namely, the size of unit area and the occupation degree. The size of unit area or unit size defines the areas by separating canvas, and the value is given as pixel size. The occupation degree is an integer used to determine whether an edge occupies the given area. For example, as shown in Figure 2, the unit size is 4, and the occupation degree is set to 2. The edges pass through three areas (a), (b), and (c). Areas (a) and (c) are identified as occupied, but area (b) is not occupied because only one pixel is passed by an edge.

By using the above parameters, a measurement called Mean Occupation Area (MOA) is proposed, as shown in equation (2).

$$MOA = \frac{1}{N} \left| \bigcup_{e \in E} O(e) \right| \quad (2)$$

where N is the number of total areas, O(e) is the set of occupied areas by edge e, and | | shows the number of elements contained by a set.

2.3. Density

The last measurement is based on the bias of the density distribution of edges. This measurement is rooted on the idea that a better edge bundling method can gather edges within a unit area, and the density per unit area is high. As a result, the distribution of the density is biased.

To show the density distribution, this study utilizes the variance in the number of pixels where the edge passes per unit area. To define the unit area, the unit size used in MOA is also used. The last measurement called Edge Density Distribution (EDD) is expressed as Equation (3).

$$EDD = \frac{1}{n} \sum_{a \in A} |p(a) - p| \quad (3)$$

where A is a set of unit areas, and $p(a)$ is the rate of the number of pixels, in which the edges pass in Area a. Moreover, p is a mean of $p(a)$. Figure 3 shows an example of EDD with four areas, and the unit size is 4. When each area is named as 1 to 4, as shown in the figure, EDD is 0.218.

3. Case Study

Figure 4 shows an example of measurements for edge bundling of 50 edges. In this study, a force-directed model is adopted to perform edge bundling. The unit size is 15, and the occupation degree is 8. As shown in Figure 4, the evaluation of edge bundling is calculated as MELD = 96.50, MOA = 0.05, and EDD = 0.085.

4. Conclusion

This research proposes three measurements to quantitatively evaluate edge bundling. The three measurements are developed using the features of edge bundling and can be used to optimize the necessary parameters to do edge bundling. For future works, the measurements will be extended for multi-type edge bundling [SY15] [PHT15].

Acknowledgement

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