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A New Taxonomy For Edge Bundling Techniques Used In Visual Clutter Reduction

Maha. Sh. Hilaiwah[1] , Aseel Shakir I. Hilaiwah[2]
[1]Al-Iraqia University College of Education for women Baghdad-Iraq
mahashakir .ibrahim@ aliraqia.edu.iq
[2]Imam A'Adhum University College Department of Fundamentals of Religion for girls Baghdad-Iraq
aseel.sh.ibrahim@imamaladham.edu.iq

Abstract

Clutter is an important and serious consideration in designing effective visualizations. It implies a disordered combination of graphical entities in the visualization. It is caused by overlapping a huge number of edges that make the visualization complex, unreadable and not useful for identifying patterns and relationships. Many actual visualization systems are designed to override the clutter problem and reduce its effects. Edge bundling is one of the strategies used for clutter reduction. Many information visualization researchers have proposed various edge bundling techniques. In this paper, we briefly explore the existing edge bundling methods and its embedding within the visualization pipeline. Also, we propose a new taxonomy for these techniques and present the main challenges of edge bundling techniques and their applications.

Keywords: information visualization, clutter reduction, edge bundling, taxonomy.

تصنيف جديد لتقنيات تجميع الحواف المستخدمة في تقليل الفوضى البصرية

خلاصة

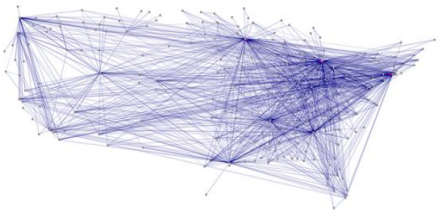
تعد الفوضى البصرية أحد الاعتبارات المهمة والجادة في تصميم تصورات فعالة. إنه يتضمن مزيجًا مضطربًا من الكيانات الرسومية في التصور. وينتج عن تداخل عدد كبير من الحواف مما يجعل التصور معقدًا وغير قابل للقراءة وغير مفيد في تحديد الأنماط والعلاقات. تم تصميم العديد من أنظمة التصور الفعلية لتجاوز مشكلة الفوضى وتقليل آثارها. تعد حزمة الحافة إحدى الاستراتيجيات المستخدمة لتقليل الفوضى. اقترح العديد من الباحثين في مجال تصور المعلومات تقنيات مختلفة لتجميع الحواف. في هذه الورقة، نستكشف بإيجاز طرق تجميع الحواف الحالية ودمجها في مسار التصور. كما نقترح تصنيفًا جديدًا لهذه التقنيات ونعرض التحديات الرئيسية لتقنيات تجميع الحواف وتطبيقاتها.

الكلمات المفتاحية: التكنولوجيا، التمثيل البصري

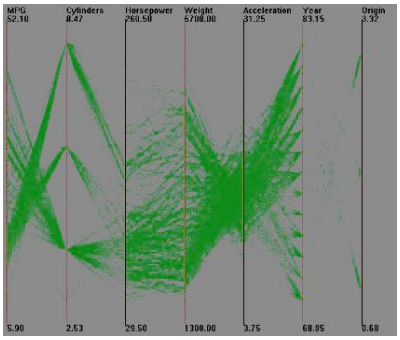
1 Introduction

A good visualization is the one that presents the desired information efficiently and accurately and thus helping the viewer to understand the information and extract patterns and relationships without difficulty or effort. But in some cases, the visualization tends to be inefficient. One of the reasons behind that is the cluttering problem, which is occurred when trying to present excessive information in a limited

display, then the resulting presentation will suffer from overlapping and disordering of visual entities as shown in the figure below.



(a)



(b)

Fig.1: visual clutter examples:(a) cluttered graph [15]
(b) cluttered parallel coordinate plots [26]

Clutter is surely undesirable since it prevents the viewers from gaining the correct information. Many researchers have suggested different techniques to overcome the visual clutter problem such as hierarchical clustering, sampling, filtering, dimensional reordering and edge bundling [9,26,4,13,7,8]. In this paper, we concerned with the edge bundling techniques.

The remainder of this paper is organized as follows: section 2 will present a review of visual clutter reduction techniques, the clutter reduction using edge bundling techniques and the embedding of the bundling process within the visualization pipeline. Section 3 will present a review of related work. Sections 4 will present the proposed taxonomy of edge bundling methods and the discussion of this taxonomy. Sections 5 and 6, will discuss the key challenges and problems in edge bundling techniques and the applications of edge bundling techniques respectively. Conclusions will be presented in Section 7.

2 Problem Definition

2.1 Visual Clutter Reduction Techniques

As mentioned before, the visual cluttering problem was caused by the overplotting of visual entities (nodes and edges). Many clutter reduction techniques was proposed and it is mainly classified into node-based clutter reduction techniques and edge-based clutter reduction techniques. In the first category, the cluttering was alleviated using various methods such as nodes clustering, changing the nodes' size, color and position. In the second category, the cluttering was reduced by processing the edge set using different techniques such as edge clustering, edge bundling, edge filtering, edge displacement and changing edge opacity. More information and taxonomy of the clutter reduction techniques could be found in [9].

2.2 A Clutter Reduction With Edge Bundling Techniques

The term “edge bundling”, was first formally declared by Holten, from the Eindhoven University of Technology in his paper " Hierarchical edge bundles: Visualization of adjacency relations in hierarchical data" [15]. He proposed a new edge bundling method which is Hierarchical Edge Bundles. After Holten contributed his technique, edge bundling concepts and ideas have been developed and proposed in diverse paradigms and for different applications [9]. In different methods of edge bundling the goal of the bundling process was to overcome the clutter problem by grouping the similar edges into bundles in such the way that the electrical wires and network cables are grouped into bundles along their joint paths and fanned out again at the end, in order to make these wires and cables easy to manage and control [15]. In this way, the edge bundling process produces the bundled visualizations with more white spaces between bundles, in order to make the visualization more readable and to ease the information interpretation and pattern extraction [10].

2.3 Embedding Edge Bundling Techniques Within The Visualization Pipeline

A visualization pipeline could be seen as a successive transformation and analysis that applied to raw data in order to produce the final visual images which could be easily perceived by the human visual system. The primary visualization pipeline model (as shown below) was presented by Card [3] and modified by Chi [5]. In this model the visualization transforms was done mainly in two stages: the first stage of transformations applied on raw data, and the second stage was applied on the visual objects (rendering), and in between these two stages was the mapping of structured data to visual objects [22].

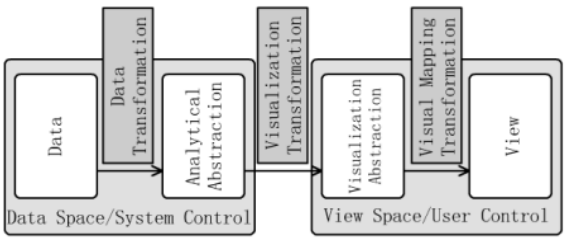


Fig.2: The visualization pipeline model [18]

The edge bundling techniques was considered as an important step in the visualization process. It could be seen as an embedded algorithm which is applied within the visualization pipeline in one or more of the following different levels:
Level 1: the edge bundling algorithms which are applied initially on the raw data. In these algorithms, the bundling process was achieved using different operations on the edge set, such as clustering, aggregation, filtering, which is mainly dependent on the edge set attributes.
Level 2: in this level the edge bundling algorithm was concerned with the mapping of the resulting structured data from the first level. The mapping process was based on the geometry of these structured data by using the associated mesh and tree construction to produce the bundled shape.
Level 3: this is the final level before viewing the final visual image. In this level, the edge bundling algorithms were based on the image processing and rendering techniques, which is applied to enhance the appearance of the final visual image.

3 Related Work

To the best of our knowledge, there is a limited effort to classify the edge bundling methods, except the work presented by H. Zhou et al. in their paper "Edge Bundling in Information
Visualization " [30], they discussed existing bundling techniques and produced a taxonomy for these methods into (cost-based, geometry-based, and image-based) as follows:

1) Cost-based methods: In cost-based edge-bundling approaches, the costs of ink or energy are used to determine the shapes of curved edges.

- *Ink minimization*: where the edges deformed and the drawing of curved edges computed by reducing the use of ink (i.e., total line length). As shown in figure 2.

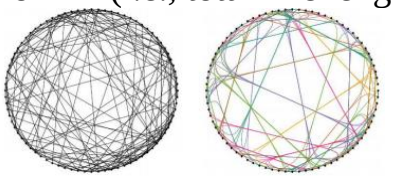


Fig.3: Cost-based edge bundling with ink minimization [14]

- *Energy minimization*: including the direction, weight, and graph connectivity in the bundling process.

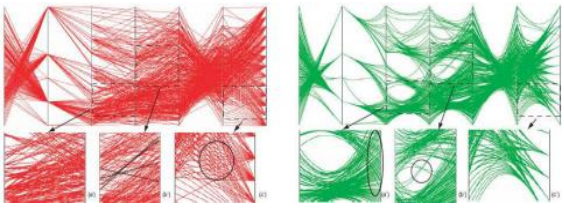


Fig.4: Energy-based edge bundling in a parallel coordinates plot[31]

2) Geometry-based methods: Large graphs can be visualized with reduced clutter using edge bundling process to redraw the similar edges. In geometry-based edge-bundling approaches, trees or grids were constructed and used as a base to determine the shapes of curved edges.

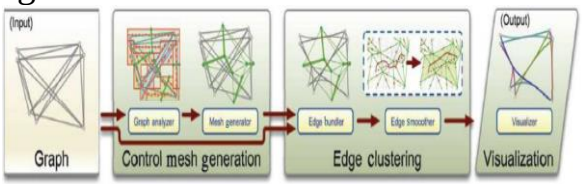


Fig.5:Geometry-based edge bundling example [6]

3) Image-based methods: These methods take advantage of the parallel computing power of modern GPUs (graphics processing unit) to speed up bundling and/or offer new visualizations for bundled graphs using rendering processes to enhance the quality of the produced visualization.

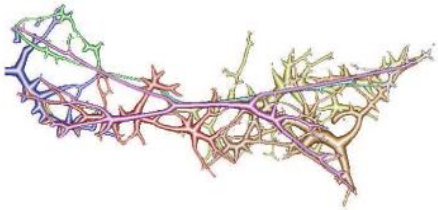


Fig.6: Example of Image based edge bundling [15]

A summarization of the taxonomy of edge bundling technique proposed in [30] was given in the following table:

Edge Bundling Techniques				
Cost-based		Geometry-based		Image-based
Ink minimization	Energy minimization	Tree-based	Grid-based	

Table1: Edge bundling techniques taxonomy proposed in [30]

4 The Proposed Taxonomy For Edge Bundling Techniques

In this paper, we proposed a new taxonomy for the existing edge bundling methods taking advantage of the previous work produced by H. Zhou et al.[30]. Our taxonomy based on different paradigms as follows:

1-Based on visualization type:

The edge bundling techniques could be classified according to the type of visualization into three types of methods:

- Edge bundling for graph visualization.
- Edge bundling for flow map visualization.
- Edge bundling for multidimensional visualization [31,19,16]

2-Based on cost minimization:

As presented in [30], edge bundling techniques could be classified into :

- Edge bundling with ink minimization techniques**.**
- Edge bundling with energy minimization techniques [31,14]

3-Based on geometry :

- Tree-based bundling techniques.
- Grid-based bundling techniques (triangle meshes, non-uniform grids) [30,6].

4-Based on image and skeleton construction:

- Image-based edge bundling as mentioned before.
- Skeleton based edge bundling, in which the bundling technique based on 2D skeletonization to construct progressively bundled layouts for general graphs [10].

5-Based on edge attributes:

- Attribute-driven edge bundling, these methods generate bundled graph layouts according to any numerical edge attributes such as directions, timestamps or weights [23][12][21].

• Traditional edge bundling. These are the other existing bundling techniques that may exclude the edge attributes.

6-Based on Temporal compatibility :

• Dynamic and Stream edge bundling methods support visual temporal analysis for the changes in the topology of the graphs over time that is changing very quickly and comes in incrementally as a stream [25].

• Static edge bundling these are the techniques proposed for static graph visualization, which provide a single coherent visual representation and does not automatically change over time.

7-Based on graph layers:

- Multilayer graph edge bundling for multilayer graphs in which the set of nodes interconnected with each other by multiple types of relations called edge layers (e.g.,

social network, biological data). In multilayer graphs visualization, the clutter problem does not only caused by a large number of edges in a graph but also by different types of edges that can overlap each other. So edge bundling techniques for multilayer graph intended to group edges from the same layer together and thus increasing the ability to extract patterns concerned to a specific layer [2,28].

- Single-layer graph edge bundling for single layer graphs in which any pair of nodes could be connected by a single edge **(layer).**

8-Based on ambiguity:

- Ambiguous edge bundling, in which the bundling methods result in a reduced clustering problem but still (ambiguous) since the bundling leads to the perception of incorrect connectivity if edges are not clearly separated within the bundles.
- Unambiguous edge bundling, these methods proposed to improve the local detailed view of a complex graph [28].

	Edge Bundling Techniques		
Based on visualization type	Edge Bundling for graph visualization	Edge Bundling for flow map visualization	Bundling for multidimensional visualization
Based on cost minimization	Edge Bundling with ink minimization	Edge Bundling with energy minimization	
Based on geometry	Tree based edge bundling	Grid based edge bundling	
Based on image and skeleton construction	Image based edge bundling	Skeleton based edge bundling	
Based on edge attributes	Attribute-driven	Traditional edge bundling	

	edge bundling	
Based on Temporal compatibility	Dynamic & Stream graph edge bundling	Static graph edge bundling
Based on graph layers	Multilayer graph edge bundling	Single layer graph edge bundling
Based on ambiguity	Unambiguous edge bundling	Ambiguous edge bundling

Table 2: the proposed taxonomy for edge bundling techniques

4.1 Discussion Of The Proposed Taxonomy:

As seen before, the preceding taxonomy for edge bundling techniques which is produced in [25], was intended to present the bundling methods in an abstract and coarse manner. In our proposed taxonomy, we tried to differentiate the edge bundling methods based on their different characteristics and using finer categorizations. Using this level of detail in our taxonomy, we tried to convey many ideas of bundling methods which are prepared to reduce the visual cluttering in different situations that achieve different requirements, such as the edges attribute, the temporal compatibility, the graph layers, and the ambiguity. And thus, the proposed taxonomy could be seen as a guide to help the intended researchers to develop an edge bundling technique taking into account the level of the visualization pipeline at which their techniques will be applied, and the requirements needed for the bundling process.

5 Key Challenges and Problems In Edge Bundling Techniques

There are some challenges that would face the developers of edge bundling methods, such as:

1-Edge bundling algorithms for general graphs are quite complex and have high computational costs. Also, most of the edge bundling techniques require rendering operation which relies on the computing power of GPUs.

2- Edge bundling techniques need to be scalable and efficient to deal with large number of edges, that is by bundling a hundreds of thousands of edges in seconds.

3- Edge bundling techniques need to consider the edge ambiguity problem which is resulted from bundling unrelated edges and thus makes the user perceive incorrect relations.

4- Edge bundling techniques need to support viewer interaction by enabling the viewer to choose from different levels of bundling and supporting multiple views.

6 Applications Of Edge Bundling Techniques

Many researchers who interested in visualizations, produced different edge bundling techniques that were dedicated to a particular application. Here we highlight some of these applications:

1-The use of graph bundling techniques to build network flow models for airspace

to support airtraffic analysis [23][29].

Fig.7: result from edge bundling process [23]

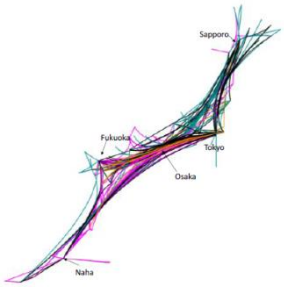


Fig.8: Result of Force-Directed Edge Bundling [29]

2-Using edge bundling technique to show full graphs of functional connectivity as well as fine details in high-resolution single-brain data [1].

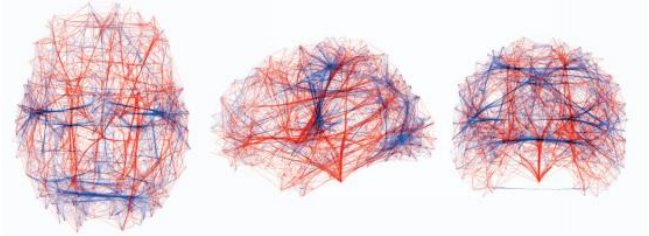


Fig.9: bundled visualization of functional connectivity in single brain [1]

3- Using the hierarchical edges bundles for the visualization of citation networks [11]

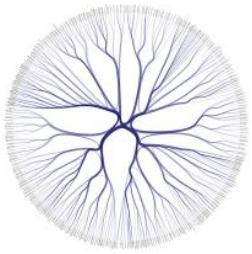


Fig. 10: graph of citation with a bundled edge [11]

4- Using edge bundling to support ontology alignment tasks [24].

Fig. 11: applying edge bundling on ontology task [24]

5- For categorical analysis of social networks with multiple edge sets.

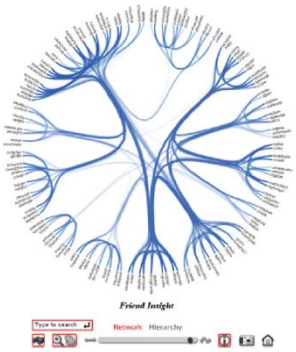


Fig. 12: facebook application -friend insight- with edge bundling [17]

6- Using edge bundling to visualize Media
Analysis Results

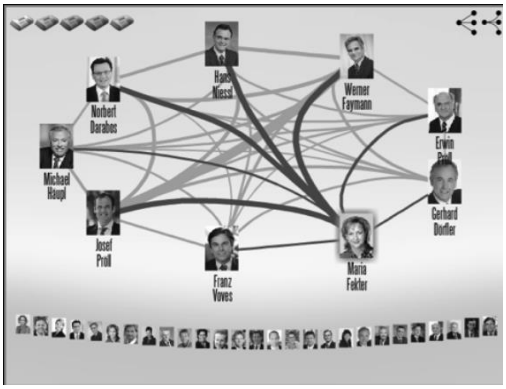


Fig. 13: APA MediaConnect Visualization with bundled edges**[]**

7- Using edge bundling techniques in Alzheimer study **[20]**

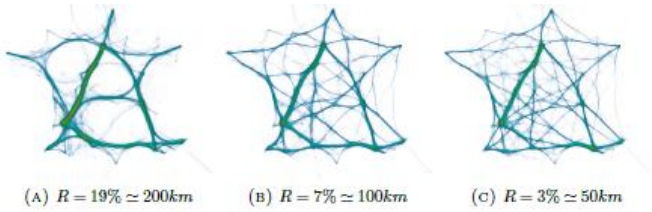


Fig. 14: Multiscale bundling of the fluency test for the control group 12 years before diagnosis of their paired subjects[20]

7 Conclusion

In this paper we presented a review of different edge bundling techniques provided for visual clutter reduction and how these techniques applied within the visualization pipeline. we proposed a new taxonomy to classify these techniques based on different paradigms. Also, we introduced different problems and challenges that may face the developers of edge bundling methods. Finally, we presented some of the applications of edge bundling that was proposed for particular tasks. we hope that researchers will find it helpful as a guide to critique and develop existing and new edge bundling techniques.

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