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ClusterVis: Visualizing Nodes Attributes in Multivariate Graphs

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ABSTRACT

Many computing applications imply dealing with network data, for example, social networks, communications and computing networks, epidemiological networks, among others. These applications are usually based on multivariate graphs, i.e., graphs in which items and relationships have multiple attributes. Most of the visualization techniques described in the literature for dealing with multivariate graphs focus either on problems associated with the visualization of topology or on problems associated with the visualization of the items' attributes. The integration of these two components (topology and multiple attributes) in a single visualization turns into a challenge due to the necessity of simultaneously representing the connections and mapping attributes possibly generating overlapping elements. Among usual strategies to overcome this legibility problem we find filtering and aggregation that makes possible a simplified representation with reduced size and density providing a general view. However, this simplification may lead to a reduction of the amount of information being displayed, while in several applications the graph details still need to be represented in order to make possible in-depth data analysis. In face of that, we propose ClusterVis, a visualization technique aiming at exploring nodes attributes pertaining to sub-graphs, which are either obtained from clustering algorithms or some user-defined criteria. The technique allows comparing attributes of nodes while keeping the representation of the relationships among them. The technique was implemented within a visualization framework and evaluated by potential users.

CCS Concepts

•Human-centered Computing → Visualization application domains → Information Visualization.

Keywords

Multivariate graphs, Information Visualization, Cluster visualization.

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1. INTRODUCTION

Information visualization techniques are aimed at providing users with interactive and visual representations of abstract data to reinforce human cognition thus enabling the users to gain knowledge about the internal structure of the data and causal relationships in it. Indeed, many fields of knowledge deals with data represented computationally as graphs and any domain that can be modeled as elements and relationships among them are potentially graphs. It is interesting to notice that, very often the elements are characterized by diverse attributes, so the dataset can be also interpreted as multidimensional data. From this combination emerge what is conventionally called multivariate graphs [15] **Erreur ! Source du renvoi introuvable.** or networks (used interchangeably here).

As show at Figure 1, multivariate graphs represent data that can be interpreted as a set of items, considered as nodes of the graphs, connected by edges, the nodes and edges having several attributes. So, a multivariate graph can be treated as (i) a multidimensional data set, composed of items that are described by several attributes (usually more than three) and (ii) as a graph, where the connections between nodes (the topology) play the central role. Thus, the visualization of multivariate graphs can be done from two perspectives: the set of multidimensional items or the graph itself, i.e., the relationships between nodes.

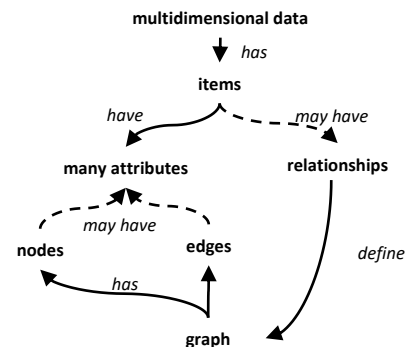


Figure 1. Multivariate graph components.

Along the years, researchers have developed many techniques for visualizing graphs [2,12,17] and multidimensional data sets [19,26]. However, applications involving multivariate graphs have become quite common in the last years, and they demand the exploration of the multidimensional data in conjunction with their topology. We find examples of these applications in areas such as

software engineering [7], social networks [18] and life sciences [16], among others.

Graphs are often represented as a node-link diagram. Indeed, many layout algorithms [1,23] have been proposed taking into account different aesthetic criteria. Nevertheless, whenever the graph has a certain number of nodes or it gets dense due to the existence of many connections among them, the node-link diagrams become less legible with overlapping nodes and many edges crisscrossed. This visual overloading gets worse if we add to the graphs nodes and edges attributes representation. Among usual strategies to overcome this legibility problem we have filtering and aggregation, which make possible a simplified representation with reduced size and density providing a general view. When applying filtering operations nodes and edges are removed from graph attending a criterion defined by the user, diagram legibility gets better. Aggregation aims collapsing a nodes set into a super node. In this operation, edges are also clustered reducing graph size and density. However, this simplification has as consequence a reduction of the amount of information being displayed while in several applications the graph details still need to be represented in order to make possible data analysis tasks.

In this work, we present the ClusterVis technique, which allows the exploration of attributes of nodes belonging to sub-graphs. The sub-graphs can be the result of some clustering algorithm or filtering or can be manually chosen by the user. The technique makes possible the comparison of nodes attributes while keeping the representation of the relationships among them. The remainder of the paper is organized as follows. In Section 2 we briefly survey related work on multivariate graphs visualization. Section 3 describes the proposed technique, while the application built as proof of concept is presented in Section 4. The evaluation experiment is described in Section 5, and conclusions and future works are drawn in the last section.

2. RELATED WORK

In recent years a varied set of techniques have been developed for multivariate graphs visualization. Some of them focus on the legibility of graph topology while others emphasize perception of attributes. One of the strategies adopted by these techniques is to use the value of attributes to define the position of nodes without taking into account the connectivity among them, which results in scatterplots [3,22,24,25]. In PivotGraph [25], nodes that have the same value for some categorical attributes are aggregated, resulting in a representation where topology is likely not preserved. NVSS [22] separates data in clusters according to the values of one of the attributes, and exhibits them in regions (scatterplots) without superposition. Both GraphDice [3] and P-SPLOM [24] use a miniature matrix of scatterplots with all possible attributes combinations, where the user can navigate and select the one he/she wants to be exhibited in the main display area. ClusterVis, although not based on scatterplots, also employs a nodes positioning strategy depending on attributes values, not taking into account the relationships. Other techniques use a complementary visualization for providing a navigation space [3, 24]. We also found that the integration of any visualization with a node-link diagram can be a very interesting solution if the goal is to analyze the topological properties of the graph [25].

Another strategy used is to combine the representations of graph structure and attributes in the same visualization area. Whilst this

strategy reduces the time needed by users to detect relationships, it might affect graph legibility due to overlapping that may occur when there are a large number of nodes. This drawback can be minimized by the use of interaction techniques. NetworkLens [14], Onion Graph [21] and the work by Elzen and Wyjk [9] uses a node-link diagram and the attributes of nodes can be explored by replacing the traditional node representation by a multidimensional visualization technique. Some techniques [8,11] combine multiple views for representing data. SocialNetSense [11], for example, uses a node-link diagram for representing a graph, a tree for displaying an existing hierarchical structure among the nodes, and TreeNetVis [10] that shows a hybrid structure formed by the network and the hierarchy in the same visualization area. In GraphTrail [8], the user can explore a graph by using different visualization techniques (tag clouds, bar charts, matrices, etc.). Graph elements can be selected in one representation for being displayed in a new view.

It is interesting to notice that although many of existing techniques make use of some clustering method as a form of simplifying the graph [8,9,20,21,25,6], they lack of a representation that allows users to visualize attributes as part of the inner cluster topology. This is the main advantage of ClusterVis in comparison with existing approaches.

3. CLUSTERVIS

The ClusterVis technique was designed for the visualization of nodes attributes belonging to clusters in multivariate graphs. The sub-graph that constitutes a cluster is meant to be obtained from a selection based on (i) a topology criteria, (ii) values of node/edge attributes, or (iii) the application of some clustering algorithm. The ultimate goal is to display many node attributes simultaneously, avoiding overlapping, and also showing the edges that represent relationships between these nodes. Figure 2 shows the ClusterVis visualization of a sub-graph obtained from a co-authorship network by filtering only the authors with most publications in Software Engineering.

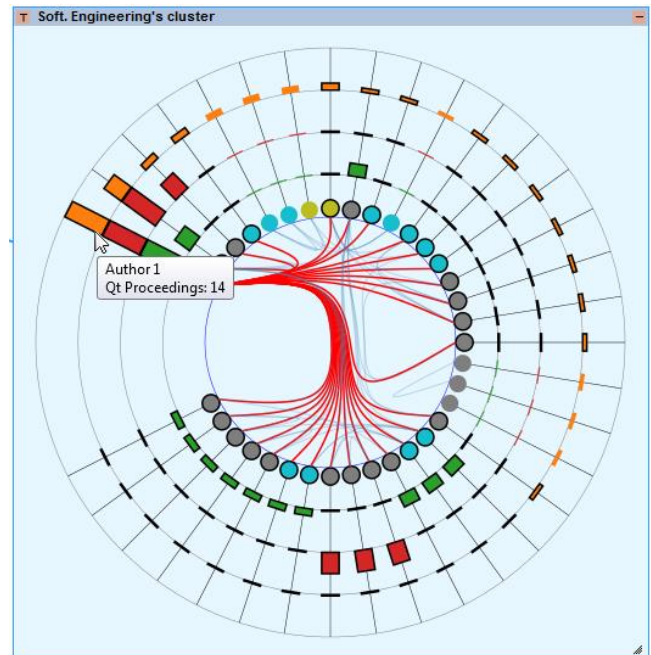


Figure 2. ClusterVis – Example with three numerical attributes (rectangles) and one categorical attribute (circle).

In ClusterVis nodes are positioned around a circle, in a radial layout. Two kinds of attributes can be exhibited: numerical attributes that are represented by rectangles with height proportional to attributes values and categorical attributes represented by small circles where each category is mapped to the circle color. The layout implemented by ClusterVis allows the comparison of values of the same attribute of different nodes as well as possible patterns within the attributes of the same node.

As we shall see at Figure 2, the categorical attribute (circle) identifies the author as professor, student or external participant, while three numerical attributes represent the number of journal articles, number of book chapters and number of conference papers published by each author. In the example, only highlighted nodes (rectangles with black borders) have publications co-authored by the selected author. The red edges represent the co-authorship relation between that author and other authors.

Each attribute is displayed in a different ring of the circle. Colors are also used to differentiate each attribute. The central area of the diagram is reserved for the display of edges that represent co-authoring relationships. They are generated by means of an approach similar to the one used in hierarchical edge bundling [13], the process we describe next. Initially, we generate a tree with a predetermined height, where the nodes distributed around the circle are considered as leaves (Figure 3). Then, the edges are drawn up using B-splines whose control points are determined using the tree nodes.

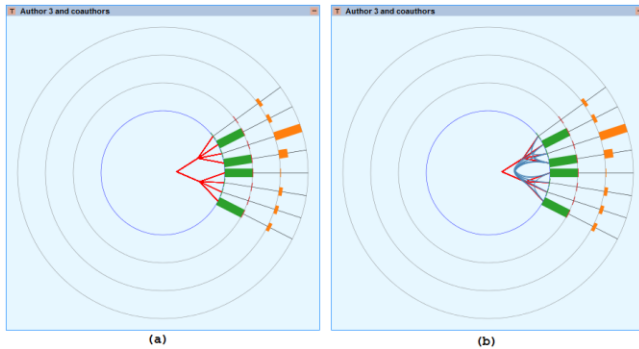


Figure 3. Rendering edges: (a) Generating tree; (b) B-splines

3.1 Interactive Features

In order to allow users to perform exploratory tasks of information datasets, ClusterVis implements user interaction both with nodes and edges in different ways. Hereafter we describe the most interesting interactive features supported by ClusterVis including (i) to select node attributes, (ii) to sort elements, (iii) to highlight edges, and (iv) to resize the graphical representation of elements.

3.1.1 Selection of Nodes Attributes

The user can select any attribute by pointing at the respective rectangle. A tooltip is displayed with the numerical value of that attribute as well as the identification of the node. In the example shown at Figure 2, the selected attribute represents the number of conference papers that author has published. The name of the author is used as node id.

3.1.2 Sorting elements

Nodes (i.e., the rectangles and/or circles representing the nodes attributes) can be distributed around the circle following an order obtained by sorting them by the value of an attribute selected by user, as for example, the total number of publications followed by the number of conference papers. When the user modifies the criterion used in such sorting, a transition between the two states is performed with animation to minimize user disorientation. The criterion selection is made by means of a combo box located in a panel associated to the view (see Figure 5).

3.1.3 Highlighted Edges

In order to facilitate the perception of nodes relationships, each time the cursor hovers onto a node by entering the area of an attribute (rectangle or circle), ClusterVis highlights in red the edges connected to the corresponding node. Furthermore, the adjacent nodes are also emphasized with black borders. Thus, to identify some subset in the displayed subgraph, the user only needs to move the cursor onto one of the nodes he/she knows that is in the desired subset.

3.1.4 Resizing Elements Representation

Users can also modify the dimensions of the main geometric elements in the representation as, for example, internal and external circles radii, the width of each ring, the width of bars representing the attributes values, and spacing among them.

3.2 Scalability Features

The size of circle used to display the ClusterVis is limited by the size of the drawing area imposed by the user and by the screen size and resolution. Thus, ClusterVis might have some scalability limitations to represent sub-graphs formed by many nodes are hard to represent. Moreover, the perception of relationships in sub-graphs might be difficult in highly connected nodes as shown at Figure 4. The edge bundling approach and the highlighting features minimize this potential problem. Other visualization techniques can be used in coordinated views to improve edges legibility.

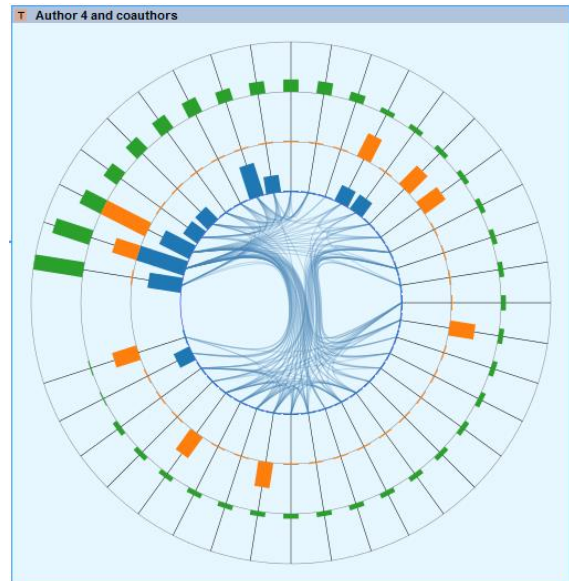


Figure 4. Edges overlapping can cause perception limitation.

4. CASE STUDY

As it is often the case, the evaluation of information visualization techniques are dependent of a tool support and a dataset. For that we have developed a dedicated tool which is the hyponym of the ClusterVis technique. The ClusterVis tool can be used to explore multivariate data issued from any application domain but for evaluation purposes we investigated it in a case study focused on the exploration of the co-authorship a network of researchers from * (omitted) built from papers published in the period 2004-2011.

Data are stored in a database from which one can obtain co-authorship graphs filtered according to many criteria as for example, year of publications and authors' main research area. Nodes can have nominal attributes (authors' names, category, main research area), quantitative attributes (total number of publications regardless of coauthoring distributed in journals, books or conferences) as well as calculated attributes based on topology (degree, closeness, and centrality). Edges representing co-authorship between two authors have quantitative attributes only, but divided in different classes: total number of co-authored publications (number of journal articles, book chapters and conference papers), idiom (number of papers written in different languages), research line (number of papers per research line), and nature (full papers, abstracts or chapters), among others.

The tool support was developed in JavaScript using D3 (Data-Driven Documents) [4]. It allows instantiating ClusterVis in several, resizable windows, so that one or more data sets can be explored at the same time. Figure 5 shows an instance of ClusterVis displaying the cluster formed by authors with research line "Conceptual Modeling" that published papers in 2011.

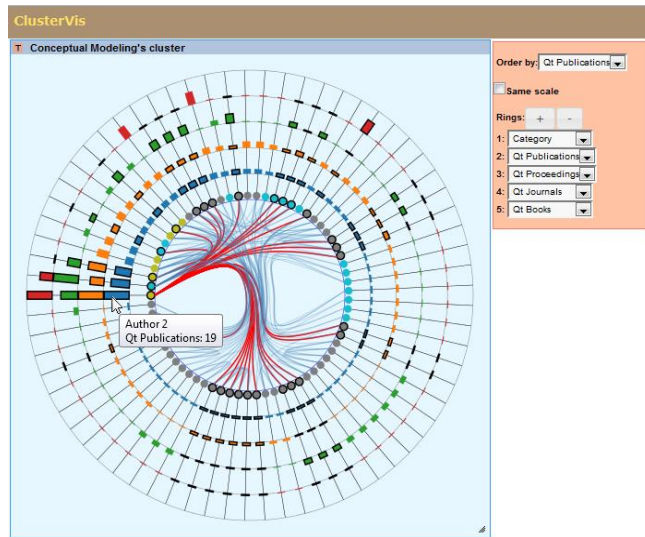


Figure 5. ClusterVis visualization of a cluster formed by authors with "Conceptual Modeling" as main research area.

As shown in Figure 5, the ClusterVis window has an associated settings panel. The panel can be freely repositioned in the working area, and contains the following options:

- (a) The ComboBox *Order by* allows choosing which attribute will be used for sorting (see Section 3.1).
- (b) The CheckBox *Same Scale*, when checked, indicates that all numerical attributes represented in the rings are visualized

with the same scale. When unchecked, it indicates that a specific scale is used for each attribute.

- (c) The buttons (+) and (-) are used to add and remove rings that represent attributes, allowing simplifying the visualization.
- (d) There is a ComboBox per rings, which allows the independent selection of the attribute to be represented in each ring.

5. EVALUATION

The evaluation of ClusterVis aimed at assessing its usability and in particular the dimensions utility of the technique whilst exploring co-authorship networks and the user satisfaction. The aspects addressed during the evaluation were: (i) interaction features available; (ii) the expression power of the graphical elements used to represent attributes in each ring as well as the additional information cues ("tooltips"); (iii) the possibility of modifying a visualization by using different sorting criteria. The evaluation was performed in remote conditions using an online survey. We consider that was a preliminary study aimed at collect user feedback about ClusterVis, for that we focused on qualitative data and we didn't measure user performance. The details about the participants, tasks and the procedures are given below.

5.1 Participants

Responding our invitation for participating in our experiment, 19 people volunteered. All of them were males distributed in the following age groups: (i) 21 to 30 years old, 85.7%, (ii) 31 to 40 years old, 9.5%, and (iii) 41 to 50 years old, 4.8%. Concerning to education, 33.3% were Computer Science (CS) undergraduate students, 57.1% had already graduated in CS and 9.6% had a M.Sc. degree in CS. Most of them (85.7%) had experience with web systems, and 61.9% stated that they had also experience with games. All users were capable of recognizing structures based on graphs, and basic knowledge about information visualization.

5.2 Tasks and initial setup

During the study, users have to use the ClusterVis and perform the following set of tasks over a co-authorship network as shown in Figure 5:

T1: Discover the name of the author with largest number of papers in Conceptual Modeling and Databases area.

T2: Verify if the author with the largest total number of papers is the same that has the largest number of journal papers.

T3: Verify if the two authors with the largest number of papers are co-authors.

T4: Verify if the author with the largest number of papers has co-authored at least one paper with authors belonging to the 3 categories (students, professors and external participants).

T5: Among the co-authors of the author with the largest number of papers, identify the professor that has the less papers than the others.

Since ClusterVis is devoted to display nodes attributes, the following mapping of data to nodes and rings was proposed to the participants in the initial setup: *blue bars*: total number of papers; *orange bars*: number of conference (proceedings) papers; *green bars*: number of journal papers; *red bars*: number of books/book chapters; for author category the mapping was: *blue circle*: student; *green circle*: professor; *grey circle*: external participant.

5.3 Evaluation procedure

The evaluation was conducted remotely. A convenience sample of participants was invited by e-mail and those who agreed to take part in the study received the instructions also by e-mail. The instructions include a description of the purpose of the ClusterVis, the purpose of the study, and how to get access to an anonymous online survey from where we get feedback from the participants.

The online survey was structured in six steps. At first, participants were asked to fill in a form with basic information about their profile. Then, in the second step, a training phase was proposed to participants. Training included an access the online version of ClusterVis and basic descriptions of how the tool works. Participants were invited to freely use the tool during 15 minutes and explore its functionalities before to proceed to the third step where they were invited to perform the tasks described in section 5.3. At the end of each task participants should provide a mark of the difficulty using a Likert scale of 5 points (from *strongly agree* to *strongly disagree*) by assessing a sentence as follows:

S1: It is easy to find out the author with the largest number of papers in Conceptual Modeling and Databases.

S2: It is easy to find out whether the author with the largest number of papers is also the one that has the largest number of journal papers.

S3: It is easy to find out whether the two authors with the largest number of papers are co-authors.

S4: It is easy to find out whether the author with the largest number of papers has co-authored at least one paper with authors belonging to one of the 3 categories (students, professors and external participants).

S5: It is easy to find out the researcher with the smallest number of papers among the co-authors of a specific author.

At the step 5 participants were invited to respond to a SUS questionnaire with their overall experience with ClusterVis. At step 6 participants were allowed to leave additional comments.

5.4 Results

The main results are summarized at Table 1. Participants provided correct answers to most of questions, the lower success rate occurred with task 5 (T5) with only 13 participants giving correct answers. This result allows us to infer that ClusterVis is utile for accomplishing exploratory tasks as proposed in the study. Assuming these result correspond to a first usage even the lower success rate of task 5 (yet 68,4%) is a promising indicator. These results are paired by a quite positive perception of task difficulty as most of the participants (above 80%) considered tasks easy to be carried with ClusterVis.

Table 1: Summary of results.

Task	Success rate	Perceived difficulty			
		Sentence	Agree	Neutral	Disagree
T1	19 (100%)	S1	17 (89,5%)	2 (10,5%)	0 (0%)
T2	19 (100%)	S2	17 (89,5%)	2 (10,5%)	0 (0%)
T3	17 (89,5%)	S3	16 (84,2%)	2 (10,5%)	1 (5,3%)
T4	19 (100%)	S4	16 (84,2%)	1 (5,3%)	2 (10,5%)
T5	13 (68,4%)	S5	17 (89,5%)	0 (0%)	2 (10,5%)

These findings are confirmed by a SUS of 76.7 (ranging from 40 to 92.5) which should be interpreted as a good indicator of usability.

The analysis of additional comments left by 11 participants allowed us to better understand what participants valued in ClusterVis. The comments left by participants were very detailed and overall they were positive. Some of them provided interesting suggestions for improvements. The identification of which node attribute is mapped to which ring is one of these issues: although each node attribute is mapped to a different ring, and colors are used to differentiate them, there is no explicit link with the attribute names that are displayed in the settings panel. One of our participants suggested the use of the same colors in the panel. Another aspect to be taken into account relates to the way more detailed information is displayed. The strategy we use (tooltips) shows an information element at a time. However, in some situations, information about many nodes has to be displayed simultaneously: one of our subjects found difficult to obtain information about related nodes (highlighted by the edges connecting them), because when moving the cursor from a node to another (activating the tooltip) the relation was lost due to the occlusion of edges. A solution to this problem could be the display of the information about all highlighted nodes.

6. CONCLUSIONS AND FUTURE WORK

In this work we presented the ClusterVis technique, which is aimed to allow the visualization of attributes of nodes while maintaining the representation of the relationships among them. The goal that we had in mind when developing the technique was to support exploration of attributes of nodes that belong to sub-graphs obtained from some clustering method applied to multivariate graphs. For that a proof of concept tool was developed and instantiated to feature an application to explore a co-authorship network. The tool is publically available online at *** (hidden for anonymity). In the current implementation, color was used for representing values of a categorical attribute, while rectangles represented quantitative attributes, with the height proportional to the value they have. Moreover, although each quantitative attribute is in a different circle, color was also used for differentiating them.

Preliminary results obtained from a remote evaluation with 19 participants demonstrated that ClusterVis might be considered usable in the present form. Although in the case study users had used only one view at a time, multiple views can be used displaying the same data or other sub-graphs for allowing comparison and further exploration.

Besides our case study with a co-authorship network, ClusterVis has been used in other case studies to visualize relationships between Network Virtual Functions provided by service providers and subscribers of these services as well as attributes of these nodes. The aim of this visualization is to support service providers' business planning tasks. (We omit the proper reference due to blind review policy)

The present implementation of ClusterVis only supports undirected graphs. Future work should include alternatives to represent directed edges. ClusterVis does not support the representation of multiple relationships, and that is another possibility of future work. We also plan to advertise ClusterVis to the community at large in order to get comments from a large

panel of users. In future studies we also want to include metrics that could be used to assess user's performance.

7. ACKNOWLEDGMENTS

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