Effects of Individual Difference on User-Sketched Layouts of Vertex-Weighted Graphs

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***Abstract*— Recent empirical works on graph drawing have analyzed users' interpretation ability with user-sketched layouts. However, user-sketched layouts have not been studied with vertex-weighted graphs. We conducted a study that was to extend the previous work to conduct an empirical study with vertex-weighted graphs. In a four-stage experiment, we analyzed characteristics of the final graph drawings, participants' drawing processes and strategies, participants' drawing preferences through questionnaires, and the differences between two groups of participants divided according to different attributes. In this paper, we report on effects of individual difference in terms of user preference, gender and prior drawing experience on user-sketched layouts of vertex-weighted graphs.**

Keywords—Graph drawing aesthetics, weighted vertex; individual difference, user-sketched graph drawing, information visualization.

I. INTRODUCTION

Layout of early graph drawing algorithms was usually determined by the intuitive aesthetics of the designers [1], [2], [3]. Therefore, there was no objective academic research comparing the degree of importance of these aesthetics. As a result, the importance of aesthetics was up to the algorithm designer and was not exactly the same between designers; therefore, there was also no way to judge the quality of these algorithms. However, by viewing from the end user's point of view, Purchase et al. [4] conducted a study evaluating how those aesthetics would aid users to understand graphs and found that minimization of the number of edge crossings is the aesthetic with the greatest influence, followed by the minimization of edge bends, and maximization of symmetry. Based on these empirical research results, algorithm designers subsequently began to value this kind of empirically tested graph drawing aesthetics. Aesthetics derived from this type of experimental results tend to be more objective and more widely accepted.

By inviting participants to take part in an experiment, the earlier research methods were to ask the participants to directly interpret the graph drawings completed by the researchers through an online system, and answer questions for every graph drawing according to experimental tasks [5], [6], [7], [8]. However, Van Ham and Rogowitz [9] proposed a new research method, in which they provided participants with different graph drawings online, and the participants were allowed to freely move the vertices in order to change the initial layout of the graph drawings, until the participant believed that a perfect presentation of the graph drawings was achieved. Following this method, Dwyer et al. [10] conducted another study, in which user generated layouts were evaluated. This study adopted two types of operation interfaces, which were multi-touch interaction on a tabletop display and mouse interaction on a desktop computer, and asked participants to move vertices to readjust the initial layout of the graph drawings.

However, previous research methods do not allow participants to freely express their thoughts. Thus, Purchase et al. [11] proposed a different evaluation method. This experiment was carried out without initial graph drawings being provided. At the start of the experiment, participants were only provided with an adjacency list of the experimental graph. Participants illustrated the complete graph drawing from scratch based on the adjacency list. This method of creating the graph drawings from scratch could avoid the initial layout of graph drawings provided to influence the final graph drawing. Furthermore, the participants' drawing process was recorded, and thus the experimental process could be analyzed. A similar approach was also adopted by Lin et al. [12], [13] to investigate how users draw clustered and symmetric graphs.

Despite the fact that deriving aesthetics based on user-generated graph drawings has been demonstrated to be useful in previous user studies, most of the studies were focused on general abstract graphs in which all vertices and edges were treated equally. How users draw weighted graphs has not been well investigated. In graph drawing, weight is an important concept and it is used to reflect the importance of vertices and edges [14], [15]. Weighted graphs have many applications in real world systems [16–21].

Hence, we conducted a user study that was to expand the body of the current research on evaluating user-generated graph drawings to include weighted graphs. The study takes the approach of asking participants to draw graphs based on adjacency lists provided and investigates how the feature of weight is drawn by users and what criteria are considered when weighted graphs are drawn. Additionally, to better understand whether users' drawing criteria change according to information provided at hand, our study has four stages and in each stage, different pieces of information were provided.

II. Experimental Method

The main research problem in this study is: “How will people present graphs when a certain vertex in the graph has higher importance?” Therefore, by means of empirical experiment, we analyze the final graph drawing presented by each participant. Furthermore, the drawing process is also our study’s research focus. Participants inadvertently reveal certain drawing strategies in the course of their drawing process. Finally, we will also collect user preference and demographic information by means of questionnaire and interview. In this paper, we report on only our findings from subjective questionnaire data.

A. Design of graphs

In this experiment, we have two experimental graphs, called Graph A and Graph B respectively, Graph A includes 10 vertices and 15 edges. Graph B includes 10 vertices and 14 edges. Both graphs are provided in the form of the adjacency list. The weight information is based on the number of edges incident to the vertex.

Our experiment is divided into four drawing experiment parts (stages): Part A, Part B, Part C, and Part D. The first two experimental graphs are both Graph A. The subsequent two experiments both use Graph B. Before the experiment however, we randomly generated the ordering of the edges in the adjacency list of the experimental graph first before giving to the participants, in order to avoid being detected by participants as the same graph. Before the experiment, aside from changing the ordering of the edges, we also gave participants different experimental tasks according to four different parts of experimental drawings.

B. Experimental tasks

Because the drawing experiment has four parts, which are respectively Part A, Part B, Part C, and Part D, we can therefore provide participants with different experimental tasks based on the four different drawing experiments as follows:

- Task for Part A: Participants are asked to draw the graph from scratch based on the adjacency list of Graph A and the task “Please draw this graph as best as you can so to make it easy to understand.”
- Task for Part B: Participants are asked to draw the graph from scratch based on the adjacency list of Graph A with a different ordering of edges from Prat A and the task “Vertex C is an important vertex and must be enlarged. Please draw this graph as best as you can so to make it easy to understand.” Note that the important vertex here has the characteristics of “connection with a large number of edges.”
- Task for Part C: This task is almost the same with Part A except the experimental graph in this part is Graph B.
- Task for Part D: Participants are asked to draw the graph from scratch based on the adjacency list of Graph B with a different ordering of edges from Prat C and the task is “Vertex A is an important vertex, although it is connected with a small number of edges. Please draw this graph as best as you can so to make it easy to understand.” Note that different from Part B, the important vertex here has the characteristic of “connection with a small number of edges”. In addition, we did not obviously ask participants to enlarge the important vertex in Part D.

C. Participants

A total of 34 participants were invited to take part in this experiment. Participants mainly came from masters’ students of National Chiao Tung University and their circle of friends and relatives. Among them, 18 were males and 16 were females. A majority of the participants are from computer science background. Nearly half of the participants had prior experience on drawing general graphs, but none of them had experience of drawing graphs of weighted nodes or edges. In addition, almost all participants frequently utilized smart phones or tablet computes in their daily lives. Thus, these participants did not have any trouble in operation of touch technology. The participants’ background information is summarized in Table I.

TABLE I. Statistics of participants’ demographic information

Attribute	Constitution
Gender	18 male, 16 female
Age	16 – 53 years old
Education	22 university or above, 12 otherwise
Occupation	19 students, 15 otherwise
Experience in drawing graphs	15 yes, 19 no
Experience in studying computer science or college mathematics	22 yes, 12 no
Degree of familiarity with touch technology	3 sometimes, 31 often

D. Apparatus and software

Mobile tablets were used to run our experimental tools and for participants to draw graphs. We have software with touch interaction installed so that participants can draw a vertex through choosing the circle pattern and then touching the screen. The vertex can be labeled by double tapping on the vertex. Edge relationships can be established by choosing the line pattern and dragging it in between two vertices. The screen recording software was also installed to record any action that the participant takes during the experiment into videos, which allows us to analyze, e.g., what actions the participant takes, or how much time it takes for the participant to operate an action.

E. Experimental procedure

Before conducting the experiment, we asked the participants to first read the experiment guidelines and inform them of the whole experimental process Only after participants completely understood the experiment guidelines and agreed to participate in the experiment did we ask participants to sign a letter of consent. Afterwards, a pre-experiment questionnaire would be filled out, in order to collect information about the participants’ background including: gender, age, educational attainment, occupation, whether there is previous graph drawing experience, whether or not participants studied computer science or college mathematics, and degree of familiarity with touch technology.

Next, we played the instructional video to demonstrate how to use the drawing software. The content of the instruction included: creating a vertex, connecting an edge between vertices, labelling the vertex with a text, enlarging/reducing the size of a vertex, moving a vertex, moving parts of the graph, deleting the selected part of the graph, and undoing the last action. Aside from the aforementioned basic drawing actions, the instructional video also had a simple tutorial example. The adjacency list in this example only had four vertices and four edges. While the instruction was being given, the content of the operation completely run through to help the participants learn. Afterwards, we will provide participants with ample time to practice and ask any related questions with regards to the relevant operation, to ensure that participants are familiar with the operation of the drawing software. The formal experiment would commence only when the participants were ready to take part in the experiment.

After participants completed the experiments, we requested participants to fill out a post-experiment questionnaire. The objective of this questionnaire was to confirm that the drawing results presented by the participants coincide with their drawing logic. This can also help us more confidently analyze the results. The content of the questionnaire included:

1) What vertex did you deem important in each part of the experiment?
2) How did you present the important vertex in each part of the experiment?
3) What was your strategy in drawing the graph in Part D?
4) In the course of drawing a graph, which characteristics were deemed important by you?
5) Did you first plan how to draw the graph in each part of the experiment?

Lastly, we scheduled additional time with each participant to conduct an interview. During the interview, it was possible to ask as many questions as possible, and seek clarification for doubtful parts.

F. Data collection

All actions which participants took during the task performance were recorded as videos by the recording software, including participants' creating or moving vertices, the time spent on operating each action, etc. These videos can allow us to analyze the drawing process in detail. Moreover, if we had questions regarding the participants' drawing process, the video could also be watched repeatedly to aid in clarifying the questions. Furthermore, the information that we have collected is based on the International Numbering Convention, e.g., the drawing generated by Participant No. 5 in Part A is named as "5A"; the drawing generated by Participant No. 11 in Part C is thus named as "11C."

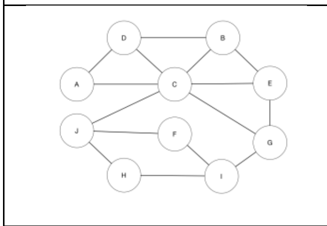
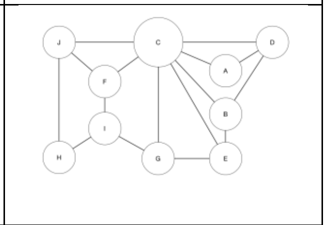
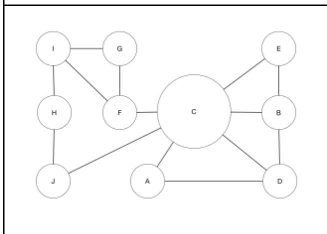
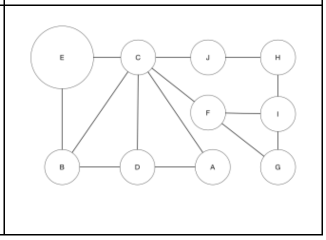
III. EXPERIMENTAL RESULTS AND DISCUSSION

By means of adopting the method described in the previous section in our experiment, we collected the final graph drawing and videos on the drawing processes of participants. In this section, we first use the resulting drawings of a participant to demonstrate the rationale and impact of our four-stage experiment design, and then report the results on participants' drawing preference, and individual differences according to two types of attributes: (1) gender, and (2) prior drawing experience, in order to analyze and compare whether there is difference between the two groups with regards to drawing.

A. Rationale of the four-stage experiment design and its impact on participants' drawing behavior

We take the experimental results of Participant No. 13 as an example, as shown in Table II. We can observe that the participant did not enlarge any vertex and did not obviously put a certain vertex in the center of the whole drawing in Part A. Note that in this part, we did not give any information on vertex weight. However, it is interesting to observe from Part A that the drawing tends to be symmetrical.

TABLE II. THE EXPERIMENTAL RESULT OF PARTICIPANT NO. 13

Part A	Part B
	
Part C	Part D
	

After Part B experiment is completed, we expected that participants can learn to utilize the characteristics of enlargement to draw a graph. Although the task for Part C does not require the participant to enlarge the important vertex, Participant No. 13 automatically found the important vertex, enlarged its size, and tended to put it in the center of the whole drawing. Concerning this phenomenon, we speculated that learning effect is present in the graph drawing of participants from Part B to Part C. Furthermore, the participant presented grid-like pattern aesthetics in the Part C drawing. We speculate that the participant thought that under the condition where there is an important vertex, grid-like pattern aesthetics is more important than symmetry maximization.

Similarly, the Part D drawing also presents a grid-like pattern. The important vertex assigned in the task was also enlarged, but it was placed at a peripheral position of the screen, to avoid the existence of edge crossings. It can be seen that for this participant, lessening edge crossings in graph drawings is more important than centering the important vertex.

B. Drawing preference

In the last stage of the experiment, we gave participants a post-experiment questionnaire and conducted interviews. At that point in time, participants could freely express their thoughts on the final graph drawing and the drawing process.

We could also raise questions at any time to help us understand each participants' drawing logic and strategy.

First, practically all participants acknowledged that the characteristics of enlarging the important vertex can cause the important vertex to be more easily distinguished. Therefore, after participating in Part B experiment, most participants learned to utilize the characteristics of enlarging the important vertex to emphasize the existence of an important vertex. Of the participants, Participant No. 5 demonstrated it most clearly. Important vertices and other vertices had a larger gap area, in order for readers to detect the important vertex at first glance. There is however, one participant (Participant No. 26) who did not believe that the characteristics of enlargement can emphasize the important vertex. Therefore, aside from Part B (which had an experimental task of enlarging the important vertex), the participant did not enlarge the important vertex in the other experimental parts.

Aside from the characteristics of enlarging the important vertex, participants can also utilize the vertex position to highlight its importance. A widely used characteristic is the practice of centering the important vertex. Participants commonly believed that the central position of the graph easily attracts attention, and therefore, they prefer to place the important vertex at the center. There were seven participants who did not believe that the vertex position and importance had a direct correlation. One of them is Participant No. 20, who cared about the aesthetics of the final drawing. Therefore, the participant presented graph drawings with symmetrical characteristics, particularly the reflectional symmetry. In a previous study [4], the importance of symmetry was ranked third. Besides, Participant No. 8 used the concept of building a house and emphasized the stability of the visual structure. Furthermore, most participants did not choose to place the artificial important vertex in Part D at the center. This is because participants attempted to lessen the edge crossings. Thus, we can infer that avoiding edge crossings is more important than centering important vertices.

The commonly discussed aesthetic, the minimization of the number of edge crossings, is a focus of this study. We can discover from the drawing process that most participants adjusted vertex positions in order to lessen edge crossings. Secondly, participants attempted to adopt commonly used aesthetics, but there are still some exceptions. For example, Participant No. 14 adopted the grid-like pattern aesthetic to illustrate the graph drawing. Therefore, the participant's drawing has a large number of vertical/horizontal edges, compared with the minimization of number of edge crossings. The participant emphasized more on the grid-like pattern aesthetic in his drawings. Participant No. 19 believed that the minimization of the number of edge crossings and the similar length of edges are equally important. Participant No. 20 believed that symmetry maximization was the most important. Participant No. 24 believed that the degree of enlargement of the vertex was most important, and different weights of vertex are given different area size, to present the difference. Thus, the participant first calculated the number of edges of each vertex, and assigned them weights accordingly before drawing. The second to that is the grid-like pattern, and the last was the aesthetic of minimization of number of edge crossings.

C. Analyses of attributes

Aside from analyzing the final graph drawing and drawing process, we also analyzed the participants' individual background and were interested in whether personal background of participants have influence on the resulting drawings and their drawing behaviors. In this present study, we based our analysis on the two attributes: gender and whether the participant had drawing experience and assessed the effect of these attributes had any difference.

First, we grouped the participants into two groups based on gender, and statistical tests were performed on these two groups of participants. The results are shown in Table III. Four characteristics had significant differences as below:

1) Important vertex centered ($p = 0.012$): Compared to females, males were more inclined to place vertices in the center (Fig. 1).
2) Planning ahead ($p = 0.043$): As opposed to males, females were more inclined to plan ahead (Fig. 1).
3) Mean area ratio ($p = 0.032$): Compared to females, males were more inclined to exaggerate the area of the vertex (Fig. 2).
4) Mean ratio of vertical edges/Horizontal edges ($p = 0.044$): Compared to males, females were more inclined to use vertical/horizontal edges (Fig. 3).

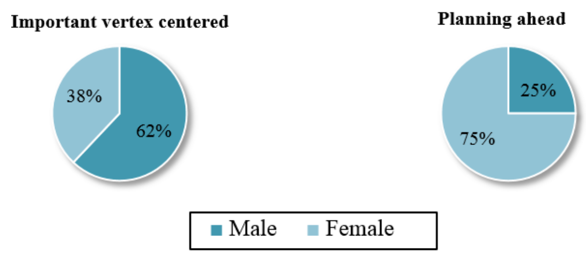


Fig. 1. The pie charts for distribution of male and female participants that drew the important vertex centered (left) and planned ahead (right).

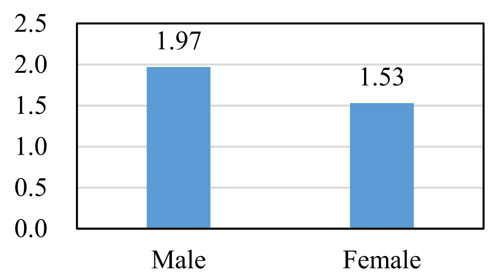


Fig. 2. Bar chart for mean area ratio for male and female participants.

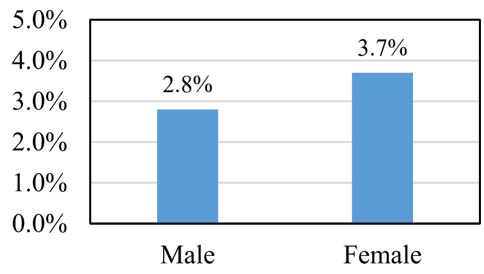


Fig. 3. Bar chart for mean ratio of vertical/horizontal edges.

TABLE III. AVOVA ANALYSIS OF ATTRIBUTES

	Gender			Experience in drawing graphs		
	Male	Female	P-value	Yes	No	P-value
Number of participants	18	16		15	19	
Number of drawings	72	64		60	76	
Final graph drawing						
Important vertex centered	49	30	0.012	39	40	0.149
Mean area ratio	1.97	1.53	0.032	1.72	1.79	0.626
Important vertex enlarged	61	50	0.325	48	63	0.668
Mean ratio of crossing edges	3.5%	3.3%	0.765	3.1%	3.7%	0.037
Mean ratio of vertical/horizontal edges	2.8%	3.7%	0.044	3.1%	3.3%	0.825
Number of no-edge-crossing drawings	56	53	0.466	53	56	0.034
Number of grid-like drawings	19	20	0.535	25	14	0.003
Drawing process						
First drawing all vertices	22	16	0.475	11	27	0.027
First drawing the important vertex	26	21	0.689	23	24	0.415
Drawing vertices based on the participant's convenience in drawing	29	22	0.482	25	26	0.376
Moving vertices or a part of the graph during the drawing process	57	47	0.435	46	58	0.962
Moving vertices after the entire graph drawing is completed	15	17	0.435	14	18	0.962
Drawing edges based on the ordering of edges in the adjacency list	69	61	0.884	57	73	0.769
Drawing a vertex and connected its adjacent edges simultaneously	3	3	0.884	3	3	0.769
Average time spent in the drawing process (sec.)	423	440	0.332	427	435	0.686
Plan how to draw before drawing the graph	3	9	0.043	6	6	0.670

From the aforementioned significant differences, we can see that males and females differ when drawing. Males are more inclined to place the graph drawing at the center to express the importance of the characteristics, and they tend to enlarge the area of an important vertex exaggeratedly. Compared to females, males emphasize that visuals should appear to be better. Furthermore, females were more inclined to plan ahead and can spend a considerable amount of time at the initial stage of the experiment. This, however, does not cause drawing time to be significantly longer than males. Because females are more inclined to plan than males, the percentage of drawings by females adopting grid-like pattern aesthetic (31.25%, 20/64) is comparatively higher than that of males (26.3%, 19/72). With regards to vertical/horizontal edges, females also utilize these more than males.

Similarly, we based our analysis on whether or not there was previous drawing experience and divided the participants into two groups, and collected the statistics for each group to test whether there is a significant difference throughout the entire experiment. The statistical software Minitab was used to perform ANOVA tests to calculate the p-value, as shown in Table III. At 95% confidence level, analyses of the four drawing experiences had significant differences as below:

1) Mean ratio of number of edge crossings ($p = 0.037$): Compared to participants with drawing experience (3.1%), participants with no drawing experience were more likely to have edge crossings in their final drawings (3.7%).

2) Number of no-edge-crossing drawings ($p = 0.034$): Compared to participants with drawing experience (88%), participants with no drawing experience were more likely to have graph drawings with edge crossings (74%).

3) Number of grid-like drawings ($p = 0.003$): Compared to participants without drawing experience (64%), participants with drawing experience was more likely to prefer grid-like patterns (36%).

4) First drawing all vertices ($p = 0.027$): Compared to participants with drawing experience (29%), participants with no drawing experience was more likely to adopt the strategy of first drawing all vertices (71%).

Concerning the aforementioned significant differences, we observed that participants with drawing experience could better prevent edge crossings compared to participants without drawing experience. They appear to be keener to minimize edge crossings. Furthermore, participants with drawing experience tend to use grid-like patterns to illustrate graph drawings. Further, these grid-like pattern graph drawings would also be visually clearer and thus utilized by more participants with drawing experience. Lastly, participants without drawing experience may lack the concept of vertex weight, and thus, may not be able to perceive the characteristic that vertices have weight. Hence, they tended to favor plotting all the vertices from the start before adjusting the graph drawing afterwards. In this analysis, we can discover that participants with drawing experience utilized more drawing aesthetics, and thus their graph drawings were also comparatively more aesthetically pleasing.

IV. CONCLUDING REMARKS

The main focus of prior empirical research on graph drawings has been on graphs in which vertices or edges have the same weight. Weighted graphs have not been well investigated from users' graph drawing point of view. In this paper, we presented a study that was to investigate how users draw weighted graphs and what the individual differences are in terms of user preference in applying aesthetic criteria and their drawing strategies. We reported the findings of individual difference in terms of user preference, gender and prior drawing experience on user-sketched layouts of vertex-weighted graphs. For the future work, we plan to continue to research effects of individual difference on graph drawing.

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