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Effects of Sociogram Drawing Conventions and Edge Crossings in Social Network Visualization

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Abstract

This paper describes a user study examining the effects of different spatial layouts on human sociogram perception. The study compares the relative effectiveness of five sociogram drawing conventions in communicating the underlying network substance, based on task performance and user preference. The impact of edge crossings is also explored by using social network specific tasks. Both quantitative and qualitative methods are employed in the study.

It was found that 1) both edge crossings and drawing conventions have significant effects on user preference and performance of finding groups, but neither has much impact on the perception of actor importance. On the other hand, node positioning and angular resolution may be more important in perceiving the importance of actors. In visualizing social networks, it is important to note that techniques that are highly preferred by users do not necessarily lead to optimal task performance. 2) the subjects have a strong preference for placing nodes on the top or in the center to highlight importance, and clustering nodes in the same group and separating clusters to highlight groups. They have tendency to believe that nodes on the top or in the center are more important, and nodes in close proximity belong to the same group.

Some preliminary recommendations for sociogram design are also proposed.

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1 Introduction

A *social network* [50] is a collection of *actors* (such as people, organizations or other social entities) and *relationships* among the actors, indicating the way in which they are connected socially (such as friendship, trade or information exchange). *Social network analysis* is a methodological approach to understanding the structure of such networks, by means of mapping and measuring these relationships. This has long been an important technique as well as a popular topic in many academic fields such as Sociology, Social Psychology, and more recently Information Visualization.

Social networks can be modeled as graphs, and visualized as node-edge diagrams where nodes represent actors, and edges represent relationships between them. With advances in display media, the use of node-edge diagrams or *sociograms* (see Figure 1 for an example) has been increasingly important and popular in social network analysis. Sociograms serve as simple visual illustrations in helping people to make sense of the underlying network information [12].

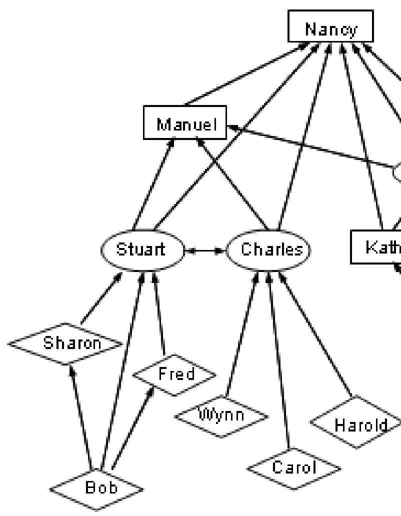


Figure 1: An advice network formed by an auditing team. Courtesy of Krackhardt (reproduced from [31], Figure 9.2). Ellipses represent managers; diamonds represent staff auditors and boxes represent secretaries. A line from Donna to Nancy indicates that Donna goes to Nancy for advice.

A network can be visualized in many different ways [6, p. 100]. When a social network is mapped to a sociogram, what matters is the relationship pattern, not the physical positioning of nodes [43, p. 64]. However, the landmark study by McGrath et al. [34] revealed that the spatial layout of nodes in a sociogram does affect human perception of social network characteristics, such as the existence of subgroups and the social positions of actors, although these characteristics are purely determined by the intrinsic network structure. This finding is significant because it indicates that people may perceive differently when a network is drawn differently.

Unfortunately, although the usage of sociograms in social network analysis can be traced back to as early as the 1930s by Moreno [39], *effectiveness* of their usage in communicating the underlying network information to the viewer has not yet received sufficient attention [35]. Currently, a considerable amount of network visualization software has been proposed in the literature [35]. Their success is mainly judged by their computational efficiency and the novelty or fanciness of the techniques they use [35, 40]. Very little empirical evidence is available to support their communication effectiveness [35].

In visualizing social networks, although it is the effective communication of network information that is important, enhanced ease of reading may facilitate the communication process [8]. A diagram is readable if its graphical elements can be easily located and their structural relationships can be easily perceived by the viewer from a graph theoretic sense. Prior research has identified *edge crossings* as an important factor affecting *readability* [40]. It is not clear, however, whether the aesthetic of edge crossings has a similar effect on performance of social network specific tasks.

The user study described in this paper aims to address the above questions. The study examines the effects of five sociogram drawing conventions and edge crossings on human sociogram perception, based on quantitative data from user preference, usability acceptance and task performance, and qualitative data from questionnaires and interviews. The specific aims of the study are:

1. To compare the relative communication effectiveness of commonly used sociogram drawing conventions.

2. To examine the effects of edge crossings for each convention.

3. To propose a set of preliminary recommendations for sociogram design.

The results and findings from this study have been reported in the conference papers [25] and [26]. This paper is an expanded version with a more detailed discussion. The remainder of this paper is organized as follows. In Section 2, related work is reviewed with a focus on studies of abstract graphs and sociograms. We also briefly introduce five social network visualization conventions, and the aesthetic of edge crossings in this section. Section 3 presents the experiment details. We report the main results and findings from the quantitative data in Section 4 and the qualitative data in Section 5, followed by a general discussion in Section 6. We discuss the limitations of this study and envision some directions for future work in Section 7. Finally Section 8 concludes the paper.

2 Background

2.1 Related Work

User studies investigating layout effects can be divided into two groups according to the graphs used: abstract graphs and domain graphs (such as sociograms, UML diagrams).

For abstract graphs, Purchase et al. [40] conducted user studies examining the individual and combined effects of graph drawing aesthetics such as symmetry, edge crossings, angular resolution and orthogonality. Subjects were required to perform path search tasks such as "How long is the shortest path between two given nodes?" One of their findings was that minimizing the number of crossings was overwhelmingly beneficial in perceiving graph structure. In an experiment that was to examine several aesthetics within the same set of computer-generated diagrams, Ware et al. [48] found that for shortest path tasks, "it is the number of edges that cross the shortest path itself that is important, rather than the total number of edge crossings in the drawing."

In investigating layout effects on sociogram perception, McGrath et al. [34] conducted a user study using five different drawings of the same network. The Euclidean distances from nodes to the center of the drawing were varied. Subjects were asked to perform social network tasks. It was found that both the network structure and the spatial positioning of nodes affected task performance. In another study, McGrath et al. [33] found that perception of network groups can be significantly affected by the visual clusters appearing in the sociogram. More recently, McGrath et al. [32] found in a study that the knowledge of the network context and experience with a particular layout could affect subjects in perceiving overall network information.

Other user studies of abstract graphs and domain graphs can be found in proceedings of the annual Symposium on Graph Drawing published by Springer and proceedings of the annual IEEE Symposium on Information Visualization. The study reported in this paper differs with the above studies in the following three aspects.

1. The impact of crossings is investigated using social network specific tasks.
2. The relative effectiveness of five specific sociogram drawing conventions is compared.
3. Both quantitative and qualitative methods are used in the study and the two types of the resulting data are analyzed in relation to each other.

2.2 Sociogram Drawing Conventions

Various sociogram drawing techniques have been proposed to highlight and communicate one or two aspects of the network structure, and at the same time, to conform to general aesthetics to improve readability. Of particular interest are the following five sociogram drawing conventions. For examples, see Tables 4, 5 and 6 in Appendix 4.

2.2.1 Circular Layout

Circular layout, in which all nodes are put on a circle, is a common technique in social network analysis. This layout is intended to highlight the relationship patterns among actors [43].

2.2.2 Radial Layout

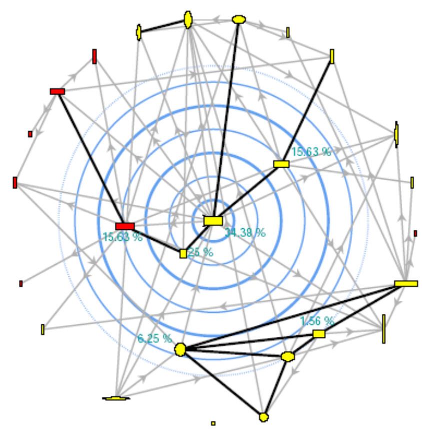


Figure 2: Radial layout of betweenness centrality. Courtesy of Brandes (from [11], Figure 7).

Brandes et al. [9] suggested a radial layout (e.g., Figure 2). This layout places nodes on the circumference of circles so that the distance from each node to the common center reflects its individual centrality level, and the nodes on the circles are arranged in a way that makes the resulting sociogram readable.

2.2.3 Hierarchical Layout

To aid people in exploring network structure and communicating information about actor status, Brandes et al. [10] proposed an explanatory layout model. This layout directly maps the status scores of actors to the vertical coordinates of nodes, and the horizontal positioning of nodes is "algorithmically" computed so that the overall readability is achieved.

2.2.4 Group Layout

Group layout (for a review, see [22]) is used to display information about groups in a network. It highlights the group existence by separating different groups and placing nodes in the same group close to each other.

2.2.5 Free Layout

This layout does not have the purpose of highlighting any particular network features. In this layout, general aesthetic principles may apply. Many automatic graph drawing methods can be used for this convention (see [16, 29]).

2.3 Edge Crossings

Edge crossings not only hide important information from the viewer, but also make the viewer reluctant to approach the diagram in the first place [16, 40]. Moreno [39, p. 141], who was the first to introduce "sociogram" into social network analysis [43, p. 9], stated, "The fewer the number of lines crossing, the better the sociogram." Bertin [6] further made it clear that,

> *"The simplest, most efficient construction (node-edge diagram: authors' note) is one which presents the fewest meaningless intersections, while preserving the groupings, oppositions, or potential orders contained in the component ... "* [6, p. 271]

Although minimizing the number of crossings has long and widely been used as a general rule in producing diagrams, it is Purchase and her colleagues who provided empirical evidence validating the aesthetic of edge crossings (see [40]).

3 Experiment

This experiment[1] aims to investigate *communication* effectiveness. That is, the experimenter knows some facts about the data *a priori*, and makes a picture to show them. The subject is expected to infer these facts from the picture. Effectiveness was measured in terms of task response time and accuracy. If the subject spends less time and completes the task with higher accuracy with, for example, one particular convention, then it could be said that this convention was more effective for that task. To have an overall understanding of the effects of drawing conventions and edge crossings, user preference and usability acceptance were also measured.

3.1 Network Measurements

For this experiment, two main social network measures [34] were considered: one is *importance* or *social status* of actors; the other is the *presence of social groups*.

There are many different approaches to measuring importance and social groups [50]. In this study, the Katz status score [28] was used as the index of importance for each actor. Relative density was chosen for measuring groups. These measurements were considered because it is thought here that both are

[1] Ethical clearance for this experiment was granted by the University of Sydney, December 2004.

close to the everyday-life notions in the context of the networks used. In particular, Katz status score is suitable for measuring importance in directed graphs since the score considers not only the number of incoming edges but also the source of the edges [28]. Relative density can be understood in an informal sense that any group member has denser connections with other members than outsiders (for a strict definition, see [38, 42]).

3.2 Subjects

Twenty-seven subjects were recruited from the student population in Computer Science on a completely voluntary basis. They were reimbursed $20 each for their time upon the completion of their tasks. The subjects were postgraduates and had experience with node-edge diagrams such as UML or ER (associated with their study units); six of them were graph drawing research students.

Novices were recruited, that is, subjects with no academic or working experience related to social networks. The reasons that subjects should be novices in this study are:

1. In communicating information about social networks, it is common, in the real world, that sociogram viewers are novices.
2. Experienced sociogram viewers likely already have knowledge about drawing conventions and edge crossings. Findings based on their responses can be biased.

3.3 Networks

Two networks were used. One was the *advice network* of Krackhardt [31]. This network has been used to compare the effectiveness of different sociogram layouts in conveying overall network information [32], and used as an example to develop the hierarchical approach [10]. The advice network can be modeled as a directed graph with fourteen nodes and twenty-three edges as shown in Figure 1. It has three groups as shown in the group layout drawings in Table 6 in Appendix 4.

Nancy	1.00	Fred	0.02
Donna	0.66	Sharon	0.02
Manuel	0.57	Harold	0.00
Stuart	0.19	Wynn	0.00
Charles	0.17	Susan	0.00
Kathy	0.08	Bob	0.00
Tanya	0.08	Carol	0.00

Table 1: Katz status scores of the actors in the advice network

The Katz status scores of the actors in the advice network [10, 28] are shown in Table 1. It can be seen that Nancy is the most important actor. Donna is the second; Manuel is the third, and so on.

The second network is a fictionalized network which was produced from the first by eliminating all the directions. This gives an undirected graph with fourteen nodes and twenty-three edges, which is called a *collaboration network*. A line between A and B means that A and B collaborate with each other. This network was used to find possible preliminary perception differences between directed and undirected networks.

3.4 Sociograms

The advice network was drawn using each of the five conventions described in Section 2.2. Two sociograms were drawn for each convention: one had the minimum number of edge crossings, and the other had many crossings. This gave five pairs of many-crossing and minimum-crossing drawings for this network (see Tables 4, 5 and 6 in Appendix 4). Note that in the radial layout drawings, only the outside circle is visible due to the expected confusion for novices and increased visual complexity if all circles were visible.

For the collaboration network, a free layout drawing with minimum crossings and a free layout drawing with many crossings were given. Therefore, only one pair of many-crossing and minimum-crossing drawings were obtained for this network.

All the nodes were labeled with different names; in each drawing, each node was mapped to a new name. By providing a context and background for each network, and names for actors, subjects were expected to perform tasks from a real world social network perspective [34]. However, subjects were not made aware that the drawings had the same graph structure.

3.5 Tasks

The experiment included three main kinds of tasks:

1. Online tasks:
   (a) Importance task: find the three most important actors and rank them according to their importance levels.
   (b) Group task: this consisted of two sub-tasks. 1) Determine how many groups there are in the network, and 2) Separate four highlighted actors according to their group membership, given the condition that no actor belongs to more than one group, and no group includes only one actor. In formal tests, the same four nodes (actors) across all the drawings were highlighted with a red rectangle each.
2. Subjective rating tasks: for the following tasks, subjects were also required to write down a short explanation for each answer.

(a) Usability acceptance rating: all the six many-crossing drawings were shown on one page (paper), and all the six minimum-crossing drawings were shown on another page. Subjects were required to rate their usability based on a scale from -3 (completely unacceptable) to +3 (completely acceptable) for importance tasks and group tasks, respectively.

(b) Crossings preference rating: each many-crossing (A) and minimum-crossing (B) pair was shown one by one, six pairs in total. Subjects needed to indicate their preferences for importance tasks and group tasks respectively, based on a scale from -2 (strongly A) to +2 (strongly B), where, for example, "strongly A" means A is strongly preferred over B.

(c) Overall usability rating: with all the ten advice network drawings being shown on one page, subjects needed to choose the three that they least preferred and the three that they most preferred for their overall usability. Then they rated the chosen drawings using a scale from -3 (the first least preferred) to -1 (the third least preferred) and from 1 (the third most preferred) to 3 (the first most preferred), respectively.

3. Questionnaires: there were two questionnaires, each having a different focus. These were presented to subjects before and after they were debriefed about edge crossings and drawing conventions. The first questionnaire asked subjects information about their background, experience with node-edge diagrams and social networks, how they interpret sociograms, and any network structure and any sociogram visual features that they thought may influence their graph perceptions. The second questionnaire asked questions about drawing conventions and edge crossings. Copies are in Appendices 1 and 2.

3.6 Online System

It is now common for sociograms to be produced automatically and displayed on screens. Social network analysis has experienced a transformation from a traditional pencil and paper basis to a computer display basis and is now normally performed online. A custom-built experimental system was developed to display sociograms online to mimic the real world setting, and to record the response speed of subjects. For the purposes of this experiment, the system did not include any interaction features. In particular, the system was designed so that:

1. A question is shown first, a button on the screen is pressed, then the corresponding drawing is shown; immediately after writing down the answer on the answer sheet provided, the button is pressed and the next question is shown, and so on.

2. The response time of each subject for each drawing and each task is logged. The clock starts once a drawing is completely displayed and ends once the button is pressed.

Note that the two group sub-tasks were presented as one question, given their close pertinence in nature (accomplishing one task can help to finish the other). Therefore, while the accuracy for the two sub-tasks was measured separately, the response time logged was for the two sub-tasks in total. The examples of screen shots are in Appendix 3.

3.7 Procedure

The formal tests took place in a computer laboratory, in which all PCs had the same specifications. Before starting the experiment, subjects were asked to read the information sheet, sign the consent form, read through and understand the tutorial material, ask questions and practice with the online system.

Once ready to start, subjects indicated so to the experimenter, and started to perform tasks formally. Ten of the twelve drawings were randomly chosen for each subject; this was because our pilot indicated that more than ten may cause fatigue. The order of group and importance questions for each drawing was randomized. Subjects were told that they could have breaks during the question-viewing periods if they wished.

After the online reading tasks there was a short break, then they proceeded with the rating tasks, followed by the first questionnaire. Next, after being given a debriefing document explaining the nature of the study, edge crossings and drawing conventions, subjects were asked to do the rating tasks (a) and (b) again. Finally the experiment finished with the second questionnaire. Subjects were also encouraged to verbalize any thoughts and feelings they had about the experiment.

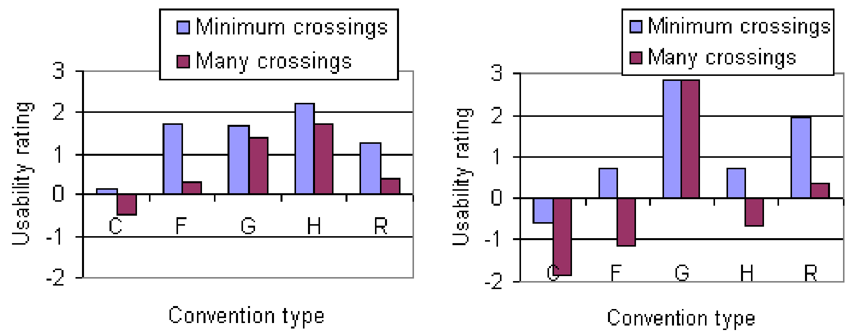
There was no time limit on task completion. During the preparation time, subjects were instructed to answer each question in the context of the underlying network and as quickly as possible without compromising accuracy. The whole session took about 60 minutes on average.

3.8 Hypotheses

Based on the prior research mentioned in Section 2, it is hypothesized that:

H 1. Group layout convention is more effective and considered as more useful than others to convey group information. Hierarchial layout convention is more effective and considered as more useful than others to convey information about importance.

H 2. For each convention, the minimum-crossing drawing is more effective, more preferred and considered as more useful than the many-crossing one.



(a) For importance tasks (b) For group tasks

Figure 3: Mean usability scores

In addition, it is always desirable that a visualization should convey to the viewer the underlying network information as much as possible. Therefore, in this study, it was also checked whether a drawing is effective in conveying other information. For example, if a convention aims for highlighting importance, then we would like to see whether it can convey group information effectively, and *vice versa*. However this is exploratory by nature, therefore there are no formal hypotheses made along these lines for this investigation.

4 Quantitative Results

The data of three subjects were discarded due to the failure to follow instructions. Since the collaboration network sociograms did not produce any distinct meaningful difference, these data were omitted from the analysis. For simplicity, C, F, G, H, and R are used to represent the **c**ircular, **f**ree, **g**roup, **h**ierarchical and **r**adial drawing conventions, respectively. P represents minimum-crossing drawings, and C many-crossing drawings. Therefore, CP denotes the circular minimum-crossing drawing; CC denotes the circular many-crossing drawing, and so on.

4.1 User Preference Data

4.1.1 Usability Acceptance

The usability rating data for importance tasks are illustrated in Figure 3(a). An *analysis of variance* with repeated measures revealed a significant effect of crossings, $F(1, 23) = 19.127, p < 0.001$, and a significant effect of convention type, $F(4, 92) = 16.653, p < 0.001$. There was also a marginally significant interaction effect, $F(4, 92) = 2.577, p = 0.043$.

Post hoc comparisons with Bonferroni corrections revealed that the impact of crossings on usability ratings was significant for the free layout convention,

	HP	HC	RP	RC	CP	CC	FP	FC	GP	GC
Pre	**2.21**	**1.75**	1.29	0.42	0.13	-0.5	1.75	0.29	1.71	1.42
Post	**2.75**	**2.29**	1.87	1.63	0.04	-0.5	1.38	0.54	1.33	1.08
p	0.04	0.05	0.00	0.00	0.77	1.00	0.08	0.27	0.13	0.12

Table 2: Mean pre- and post-debriefing ratings for importance tasks

	RP	CC	FC	HC
Pre	1.96	-1.83	-1.13	-0.67
Post	1.50	-1.43	-0.54	-0.08
p	0.02	0.03	0.02	0.02

Table 3: Mean pre- and post-debriefing ratings for group tasks (only data with significant changes are shown)

$F(1, 23) = 20.979, p < 0.01$, and for the radial layout convention, $F(1, 23) = 9.915, p < 0.01$.

A similar post hoc procedure with all the minimum-crossing drawings showed that HP was considered as significantly more useful than RP, $F(1, 23) = 9.308, p < 0.01$, and than CP, $F(1, 23) = 23.074, p < 0.01$.

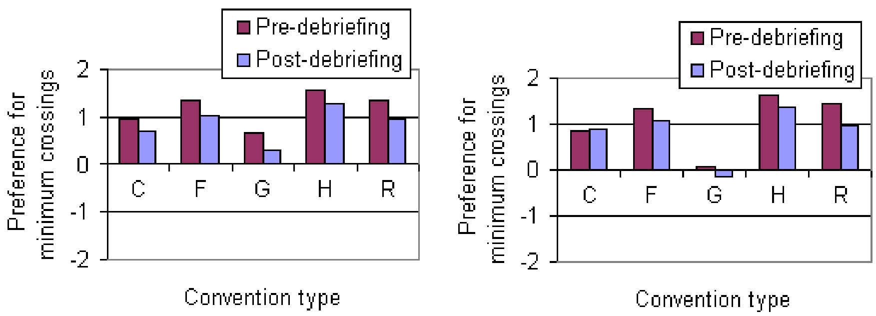
Furthermore, the *paired t tests* showed that after debriefing, there was a significant increase in usability ratings for each of the hierarchical and radial layout drawings (see Table 2). In particular, both HP and HC were rated higher than all the others in the pre- and post-debriefing ratings, suggesting that the aesthetic of edge crossings was perceived as less important than the positioning of nodes for importance tasks.

The usability rating data for group tasks are illustrated in Figure 3(b). An analysis of variance with repeated measures revealed a significant effect of crossings, $F(1, 23) = 46.160, p < 0.001$, and a significant effect of convention type, $F(4, 92) = 59.271, p < 0.001$. There was also a significant interaction effect, $F(4, 92) = 6.368, p < 0.001$.

Post hoc comparisons with Bonferroni corrections revealed that crossings had a significant effect for the free layout convention, $F(1, 23) = 35.526, p < 0.01$, for the radial layout convention, $F(1, 23) = 38.619, p < 0.01$, for the circular layout convention, $F(1, 23) = 7.667, p < 0.05$, and for the hierarchical layout convention, $F(1, 23) = 17.355, p < 0.01$, but not for the group layout convention.

A similar post hoc procedure with all the minimum-crossing drawings showed that as expected, GP was considered as significantly more useful than RP, $F(1, 23) = 22.691, p < 0.01$, than CP, $F(1, 23) = 71.731, p < 0.01$, than HP, $F(1, 23) = 35.319, p < 0.01$, and than FP, $F(1, 23) = 70.813, p < 0.01$. It can be seen from Figure 3(b) that both GC and GP were rated much higher than others; in fact the others were perceived as having little usefulness.

The paired t tests showed that after debriefing, there was a significant decrease in usability ratings for RP, and a significant increase for CC, FC and HC,



(a) For importance tasks (b) For group tasks

Figure 4: Mean preference scores

respectively (see Table 3).

4.1.2 Crossings Preference

As can be seen from Figure 4, generally, the subjects preferred the minimum-crossing drawing more than the many-crossing one for each convention. The *1-sample t tests* against the hypothesized mean (=0) revealed that for each convention except the group layout convention, this preference was statistically significant ($p < 0.01$).

The paired t tests revealed that the pre- and post-debriefing ratings were not significantly different for each convention, although the post-debriefing preference was generally weaker than the pre-debriefing one. In particular, after debriefing, the subjects preferred the group layout drawing with many crossings slightly more than its minimum-crossing counterpart for group tasks (see Figure 4(b)).

4.1.3 Overall Usability Rating

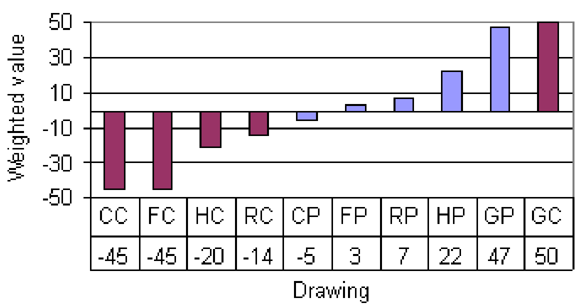
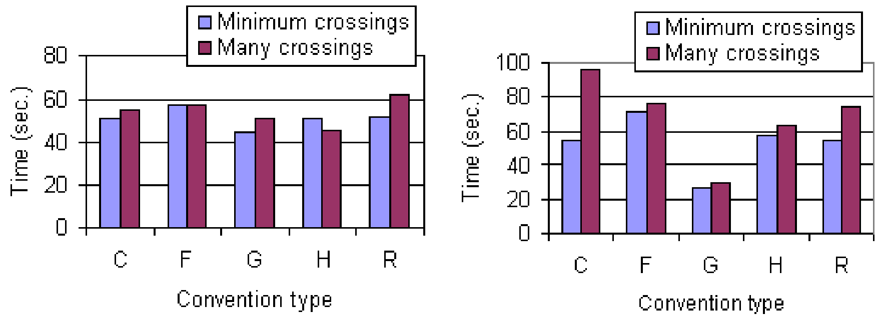


Figure 5: Weighted values of ratings for overall usability



(a) For importance tasks (b) For group tasks

Figure 6: Median times

The rating scores for each drawing were summed as a weighted value, and the weighted values for all the drawings are shown in Figure 5. It can be seen that generally, the many-crossing drawings were considered as being less useful except GC. GC was rated the highest for its overall usability, followed by GP, then HP. Both CC and FC had the lowest weighted value, indicating that they were considered as having little overall utility.

4.2 Response Time Data

The response times were not normally distributed. Therefore the time data were normalized using a log transformation before they were analyzed [44]. The median times are summarized in Figure 6.

For importance tasks, an analysis of variance with repeated measures revealed a significant effect of convention type, $F(4, 92) = 4.179, p < 0.001$. The impact of crossings was not significant, $F(1, 23) = 0.302, p > 0.50$.

Post hoc comparisons with Bonferroni corrections were made with all the minimum-crossing drawings. It was revealed that the hierarchical layout convention was not significantly better than any of the other conventions. The only significant effect found was that a shorter time was spent with the group layout convention than with the free layout convention, $F(1, 23) = 14.428, p < 0.05$.

For group tasks, an analysis of variance with repeated measures revealed a significant effect of crossings, $F(1, 23) = 21.050, p < 0.01$, and a significant effect of convention type, $F(4, 92) = 30.206, p < 0.001$.

Post hoc comparisons with Bonferroni corrections revealed that the impact of crossings on response times was significant for the circular layout convention, $F(1, 23) = 10.675, p < 0.01$, and for the radial layout convention, $F(1, 23) = 10.441, p < 0.01$.

A similar post hoc procedure with all the minimum-crossing drawings showed that as expected, the subjects spent a significantly shorter time with GP than with HP, $F(1, 23) = 26.587, p < 0.01$, than with RP, $F(1, 23) = 44.589, p < 0.01$, than with FP, $F(1, 23) = 64.540, p < 0.01$, and than with CP, $F(1, 23) =$

$26.797, p < 0.01$.

4.3 Response Accuracy Data

4.3.1 Reported Group Number and Member Group Assignment

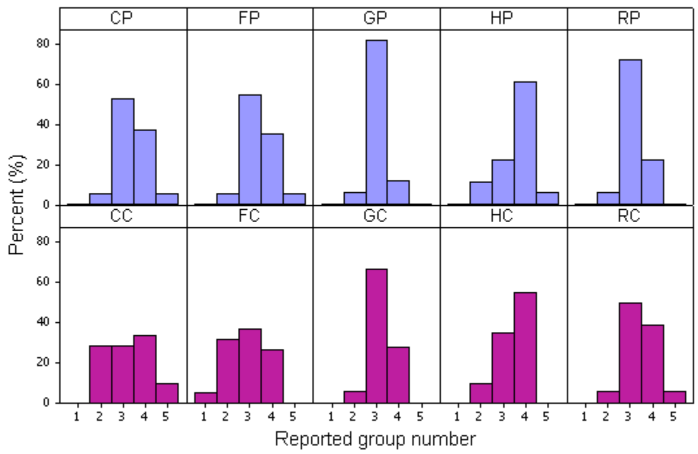


Figure 7: Distributions of reported group number

Figure 7 illustrates the distribution of the reported group number for each drawing. As can be seen, GP had the largest proportion of the subjects (82.4%) reporting the group number "correctly"(three as expected). Considering the distribution shape, it can be seen from Figure 7 that the many-crossing drawing generally had a flatter distribution than the minimum-crossing one for each convention. This suggests that crossings make it harder to convey the group information *consistently* to the viewer [34]. An analysis of variance with repeated measures on the reported group number showed that there was a difference at the 0.066 level of significance.

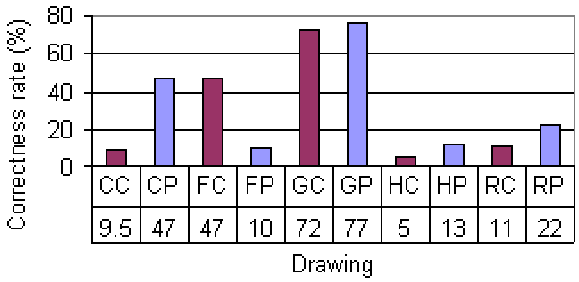


Figure 8: Group assignment correctness rates

Also, at the dyad level, the member group assignment task was to investigate the impact of crossings and convention type on human perception of the co-memberships of actors. As can be seen from Figure 8, a higher correctness rate was obtained with the minimum-crossing drawing for each convention except the free layout convention. Both GP and GC yielded the highest correctness rates (76.5% and 72.2% respectively).

4.3.2 Identifying Most Important Actors

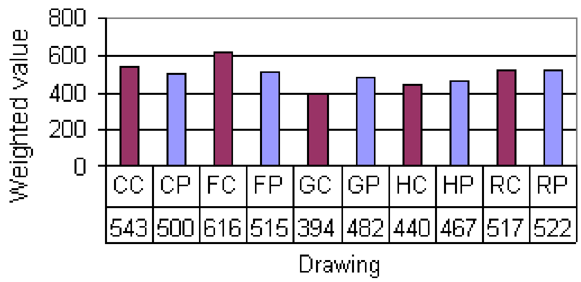


Figure 9: Weighted values of response accuracy for identifying important actors

The response accuracy for each drawing was calculated as a weighted value and summarized in Figure 9. The weighted value is to measure the overall effectiveness of a drawing in conveying information about importance. It is calculated in the following way. First an index of 5 is given to the most important actor, 2 to the second and 1 to the third; then the productions of indices and corresponding correctness percentages are summed as a weighted value for each drawing. As can be seen from Figure 9, surprisingly, it is FC that had the highest weighted value, not HP or HC.

4.4 Summary and Discussion

Analysis of the quantitative data revealed that our hypotheses were only partly confirmed.

There was strong evidence suggesting that crossings had significant effects on crossings preference, usability acceptance, and group task performance, but not on importance task performance.

With respect to drawing conventions, there were significant effects of convention type on usability acceptance and group task performance. Again, no pronounced evidence was detected suggesting that importance task performance was significantly affected.

For importance tasks, the hierarchical convention was strongly preferred, while for group tasks, the group convention was strongly preferred. The subjects achieved the highest response accuracy with the group convention for group tasks. However, the highest response accuracy did not come with the hierarchical convention for importance tasks. For overall usability, the group convention was the one for which usability was rated high and task performance was also good.

Quite surprisingly, the subjects were overwhelmingly in favor of the hierarchical convention for importance tasks. They spent a relatively short time with HP, but obtained the lowest correctness rate among all the minimum-crossing drawings. On the other hand, the highest correctness rate was achieved with FC, but a relatively long time was spent with it. We realized that during the experiment, some subjects had complained that in some drawings, edges were incident to nodes too closely to clearly identify arrow directions. Visual inspections revealed that indeed, the free layout drawings had very good node angular resolution, while the hierarchical convention made angular resolution relatively low, where edges had to be crowded on the two sides of nodes. In addition, the subjects spent a longer time with FC than they did with HP. This might actually allow them a better chance of understanding the network structure correctly with FC.

From Figures 6(a) and 9, it can also be seen that for importance tasks, there were no clear consistent patterns in terms of either edge crossings or convention type. The subjects generally performed better when they took longer times. We conjecture that crossings are important only when path or edge tracing is involved, such as finding groups. On the other hand, for communicating information about importance, node positioning and angular resolution may be more important, compared to reducing the number of edge crossings and spatial arrangement in terms of drawing conventions.

5 Qualitative Results

5.1 Visual Factors in Sociogram Perception

The following categories were used to present the results of the questionnaires. For more details on the qualitative data, see [26].

Category 1: What factors did you consider when determining your answers?

Almost everyone responded that only actual relationships should be considered.

Category 2: Did layout affect you when trying to find answers?

About 85% of the subjects indicated that their final answers were determined by both network structure and sociogram layout. For example, "50% relations, 50% layout"; "A little bit layout"; "Try my best to find the answer according to relations; when the graph is confusing, I will rely upon the layout", etc. One subject said "only layout of drawing". The rest of the subjects indicated that their answers were only determined by relations. They gave responses such as "The final answers are probably similar, but a bad layout needs more time to understand the answer"; "If a layout is nicer and clearer, I could answer questions faster", etc.

Category 3: What visual features help or hinder you to perform better?

Nodes and edges should be carefully organized and treated according to the visualization purposes and their individual roles in the network. For example, nodes should not be evenly distributed; the distances between nodes should reflect their relationships; arrows should point to the same direction. Here are some comments: "Some important people are crowded with others"; "When relationship dependency makes a cycle, it is difficult to judge who is more important"; "Hierarchy layout really helps to find the important people"; "Whether a node is important or not depends on edges it has, not on its position in the diagram", etc.

Category 4: How to highlight importance and groups?

Most of the subjects preferred putting nodes on the top to highlight importance; some mentioned putting nodes in the center and separating them with others. Almost everyone agreed that highly linked nodes should be visually grouped together. Some examples are: "Clustering groups 'correctly' helps"; "Placing important people on the top or in the center helps"; "Groups should be clearly separated"; "Low degree nodes on the top should be avoided", etc.

5.2 Sociogram Perception Conventions and Design Recommendations

The analysis of the qualitative data revealed that the subjects had *perception conventions*. They had a strong preference for placing nodes on the top or in the center to highlight importance, and a preference for clustering nodes in the same group and separating clusters to highlight groups. They also had tendency to believe that nodes on the top or in the center are more important, and nodes in close proximity belong to the same group.

In terms of sociogram design guidelines, there are many sets of aesthetic rules available for drawing graphs. In [46, p. 13], Sugiyama summarizes twenty-nine rules for drawing general graphs, classified as *semantic rules* and *structural rules*. Other sets of rules are given by [3, 16, 21, 49]. More specifically, Brandes et al. [8, p. 96] mention some criteria for visualizing social networks. For example, groups are visually separated; edges are uniform in length. Those rules, or aesthetic criteria, are mainly based on common senses and the opinions of experts. In this study, we derived a set of sociogram design recommendations based on the experimental results and listed them below. It is believed that design guidelines generated on empirical bases should be more beneficial in facilitating human sociogram perception.

1. "Do not" rules
    - (a) Do not distribute nodes randomly.
    - (b) Do not treat nodes (and edges) equally or distribute nodes evenly [2, 15, 30].

   (c) Do not cross edges haphazardly.

2. Task-independent rules

   (a) Reduce the number of crossings [4, 36].
   (b) Keep edges short and nodes adjacent when the underlying relationships are close [19].
   (c) Arrange arrows to point to the same direction or in patterns [18, 27].
   (d) Provide additional visual hints when necessary.

3. Rules for group tasks

   (a) Cluster nodes that belong to the same group [7, 20].
   (b) Separate groups spatially [24, 38, 45] or by adding boundaries [47].
   (c) Cross edges in a group to highlight group information [5].

4. Rules for importance tasks

   (a) Highlight importance using hierarchical [10] or radial layout [1, 9].
   (b) Increase node angular resolution [17].
   (c) Put important nodes on the top or in the center.
   (d) Highlight important nodes by using color, size, etc. [23].
   (e) Separate important nodes with others.

In visualizing social networks, there is an increasing demand for automatic methods. For this purpose, we have cited some example algorithms which are (or potentially are) useful for implementing these rules. For more information about graph drawing algorithms, the reader is referred to proceedings of the annual Symposium on Graph Drawing published by Springer and proceedings of the annual IEEE Symposium on Information Visualization, and books [16, 29, 46].

In addition, these rules often have competitive relationships in drawing sociograms and designing algorithms. Mostly it is impossible to implement all the rules at once. The final layout is often a combination, in which each rule has its own weight according to its individual importance [8]. As such, it is necessary to have clear priorities between these rules in advance [40, 46]. Specific priorities can be set based on the specific needs of an application or the goals that an algorithm is designed to achieve. General priorities can also be built based on empirical evidence [40], general discussions [21], or theoretical considerations [46]. Here we took the theoretical approach of Sugiyama for setting priorities among these rules (for details, see [46, p. 15-16]). The rules were divided into four groups and ordered from high to low in priority as follows: "Do not" rules, task-independent rules, and task-dependent rules (rules for group tasks and rules for importance tasks). In each of the four groups, rules were also ordered from high to low in priority as they appear in the list above.

6 General Discussion

6.1 Perception Convention, Sociogram Layout and Network Structure

This study provides additional empirical evidence for the prior finding that human sociogram perception can be affected by not only the intrinsic network structure, but also sociogram layout [34]. This study also found that people have conventions in sociogram perception, as described in Section 5.2.

In the study of McGrath et al. [34], it was found that the Euclidean distance of a node to the center of the sociogram has a negative impact on the perceived node importance. This was supported by the qualitative results. This finding can be explained by one of the sociogram perception conventions found in this study. That is, the subjects tended to perceive nodes in the center as being more important. On the other hand, in our study, the radial layout places important nodes in or near the center. However, task performance with the radial layout drawings was not significantly better than that with the other drawings. This indicated that the actual status of a node in the network and its Euclidean distance to the center of the sociogram are not the only factors determining the perceived node importance. We believe that local spatial features, such as whether the node in question is well separated from the others, and global features, such as whether all nodes are treated according to their individual status, all have their roles in sociogram perception.

It is well known that people have conventions in interpreting and comprehending graphics. For example, people tend to read graphics from left to right and from top to bottom, which was found attributable to their daily English reading habits [37, 51]. Winn et al. [51] found in a study that when the object on the left was linked by the right object, the left object was "consistently" deemed as the cause, rather than the effect of the right one.

Despite this, it is important to bear in mind that solely relying on perception conventions on spatial layout to communicate network information can be at risk of failure. After all, grouping and importance are completely determined by the intrinsic network structure. It is believed that the effects of the perception conventions are limited. Further, according to McGrath et al. [34], the perceived importance of nodes that are structurally less important is more sensitive to the node positioning than that of structurally more important nodes. That is, there is an interaction between perception convention and network structure. Both ignorance and exaggeration of the role of human perception conventions in sociogram perception can make quality communication difficult. As a result, a good visualization should respect these perception conventions. When a sociogram is presented in a way that is inconsistent with these conventions, it is reasonable to expect that degraded performance will occur (although they are not necessarily determining factors).

Also, further studies are needed to understand how these perception conventions work, so that we can find a way either to avoid the bias introduced by them [34], or take advantage of them in exchange of information.

6.2 Drawing Conventions and Edge Crossings

This study extends the prior research on layout effects with respect to two aspects.

First, it compares the relative effectiveness of the five sociogram drawing conventions. For group tasks, the group layout was the only one that was perceived as high in usability, and had outstanding performance as well; this suggests its compelling superiority over the other types of layouts in conveying group information.

For importance tasks, effectiveness of the radial layout of the given format in this study was questionable. Actually, very few subjects realized that the nodes were arranged radially. One of the major advantages for the radial layout is that this layout uses space effectively [6], thus scaling better with the size of networks than the hierarchial layout. Further investigations are needed to fully take advantage of this layout.

On the other hand, the hierarchial layout was the one that was perceived as high in usability and low in difficulty (response time), but the actual response accuracy was not optimal. Closer inspection reveals that node angular resolution, a confounding factor, interfered with the task performing process (although a strong conclusion could not be drawn about this). This was unexpected, since it was taken for granted that, the strong match between spatial and structural hierarchy should facilitate human understanding, irrespective of angular resolution. There are a number of ways to improve node angular resolution (e.g., [17]); in the context of social networks, a simple trick is to use node size to reflect the number of edges incident to the node. Using node size, angular resolution does not deteriorate with the increase in the number of edges incident to the node. Further, in the resulting sociogram, while keeping angular resolution stable, both node size and position highlight importance. Although its actual effectiveness needs to be examined with further studies, according to "say it again" principle [41] and "friendly redundancy" [14], better user performance with this revised hierarchical layout is expected.

It is important to make it clear that a particular drawing convention for example, the group layout, is relatively more effective in conveying group information than other conventions. It may not, however, be equally effective when a different group criterion is used. As mentioned previously, the same network feature can be measured using different criteria [50]. For instance, importance can be measured according to betweenness centrality, or degree centrality. However, in the hierarchical layout, the betweenness measure does not have a spatial mapping as straightforward as the degree measure has, even if the hierarchical arrangement may give some limited hints; for betweenness centrality, the two separated subgroups associated with the node considered may not be readily evident in the hierarchical layout. Empirical evidence for this can also be found in [34].

Secondly, this study examines the effects of edge crossings on sociogram perception using social network specific tasks. Consistent with prior research (e.g., [40]), edge crossings are undesirable in sociograms, and affect group task performance negatively. However, there was no apparent effects of crossings found for importance tasks. Based on the analysis of task cognitive processes and comments from the subjects, the absence of impact may be due to the fact that little edge tracing was required in performing the importance tasks. In other words, crossings matter only if intensive edge tracing is involved. This finding is new but should not come as a big surprise, since in prior research (e.g., [40, 48]), path search tasks were mainly used in investigating the effects of crossings.

6.3 Sociogram Design Recommendations

This study proposes a set of design recommendations for social network visualization described in section 5.2. These recommendations were derived mainly from the qualitative data for performing importance and group tasks; they need confirmation with further studies and refinement as our understanding about human sociogram perception improves. However, the design recommendations may serve as a starting point and a preliminary basis for further development of design guidelines.

It is important to note that these design recommendations were derived from the responses of novices. Human perception behavior can be influenced by both the visual features of the sociogram and the expertise of the viewer. The former affects the behavior in a bottom-up fashion while the latter in a top-down manner. We suspect that the lack of prior knowledge makes novices tend to apply their general perception conventions in performing tasks. In other words, the spatial arrangement of nodes may have a stronger impact on novices than on experts. As such, in response to the request to avoid the bias caused by perception conventions, which we mentioned above, one possible way might be to pre-train and pre-inform novice viewers about the visualization method used. With the increase of experience in sociogram perception and knowledge about network substance, in the end, the bottom-up impact can be overridden by the top-down one.

6.4 Summary

The findings obtained in this study make it clear that there is no universal best representation existing for a network [34]. Whether a visualization is good or bad makes sense only when it is related to particular tasks and a target audience. As a general rule of thumb, in producing sociograms, it is necessary to be aware that:

1. The effects of human perception conventions are limited. They may vary with the prominence level of the network feature in question, and the expertise of the audience.

2. Care should be taken for trade-offs between aesthetic criteria. Implementing one aesthetic at the cost of another may cause unexpected consequences.

7 Limitations and Future Work

The limitations of the study lie in two primary categories. The first category of limitations are methodological and common in general evaluations. For example, subjects are likely to behave differently from the way they do in their daily lives, when explicitly asked to perform online tasks in an experiment [13].

The second category of limitations are related to experimental settings and may be addressed in future work. For example, only a single small network was used in the study. This may limit the generality of the findings obtained. In addition, the number of subjects and trails was relatively small.

Despite these limitations, the significance of this study itself and its findings should not be overshadowed. The study was designed to meet the urgent need for empirical work, to catch up with the progress made in social network visualization techniques [35]. Apart from those discussed in Section 6, an additional contribution is that, we believe, this study has pointed out several interesting directions for future work. For example,

1. To replicate and confirm the findings obtained in the current study using networks of different sizes and contexts.

2. To investigate the effects of drawing conventions and edge crossings on experts in exploring networks.

3. The sociogram perception conventions were derived mainly based on qualitative data. These conventions need confirmation from quantitative evidence.

8 Conclusion

This study builds on and extends the work of McGrath et al. [33, 34] on human sociogram perception and the work of Purchase et al. [40] on the effects of edge crossings. The results of this study add to the growing body of evidence suggesting that spatial layout has an important role in communicating network substance effectively. This study, together with prior research (e.g., [32, 33, 34]), has demonstrated how sensitive the human sociogram perception is to spatial layout and how important it is to have visualization techniques evaluated for their actual communication effectiveness. It should be noted that visualization techniques, which are highly preferred by users, do not necessarily always lead to optimal task performance, as demonstrated in this study.

The findings from this study should be interpreted within the limitations of the given experimental setting. In this study we had only investigated the relative effectiveness of five “explanatory visualization” [10] conventions and the impact of edge crossings under each convention, in communicating information about actor status and groups to novices. Their usability in assisting professionals to explore and understand social networks remains untouched and is beyond the scope of this study. For a comprehensive overview in this field, see [12].

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Appendices

1 Questionnaire 1

1. What is the status of your enrolment (e.g., 2nd year computer science undergraduate)?
2. Do you have any experience (study/working) with node-edge diagrams (e.g., UML, ER, etc.). If yes, please give details.
3. Any experience about social networks? If yes, please give details.
4. What factors did you consider when you tried to identify who is most important and how many groups?
5. Did you answer questions according to 1) their relationships, or 2) the layout of the drawing, or 3) both?
6. Does layout affect you when you try to find answers? What impacts are they and how?
7. Are there any drawing features which you think would help you to find who is most important? Please give details.
8. Are there any drawing features which you think are not helpful in finding who is most important? Please give details.
9. Are there any drawing features which you think would help you to find groups? Please give details.
10. Are there any drawing features which you think are not helpful in finding groups? Please give details.
11. Any other comments and recommendations about how to draw social networks to help you to easily read graphs and understand the social network?

2 Questionnaire 2

1. Now you have known that there are 5 different social network drawing conventions: hierarchical, circular, radial, group, and free layout. Each convention is proposed to highlight one aspect of social network structure.
   (a) Do you think these conventions serve their purposes properly?
   (b) When you identify who is the most important, putting the most important one in the center or on the top really helps?
   (c) Are you apt to consider those in the center or on the top in a drawing more important?

(d) When you identify how many groups there are in the network, grouping them together really helps?

(e) Are you apt to consider that nodes which are close to each other belong to the same group?

(f) Do you have any other suggestions on how to highlight network features: group, importance, overall readability, etc.?

2. Under these conventions, the network can be drawn with many crossings or very few crossings as we did in the study. Edge crossings really matter? When do crossings matter and how?

3. Any other thoughts/comments?

3 Screen Shots of the Online System

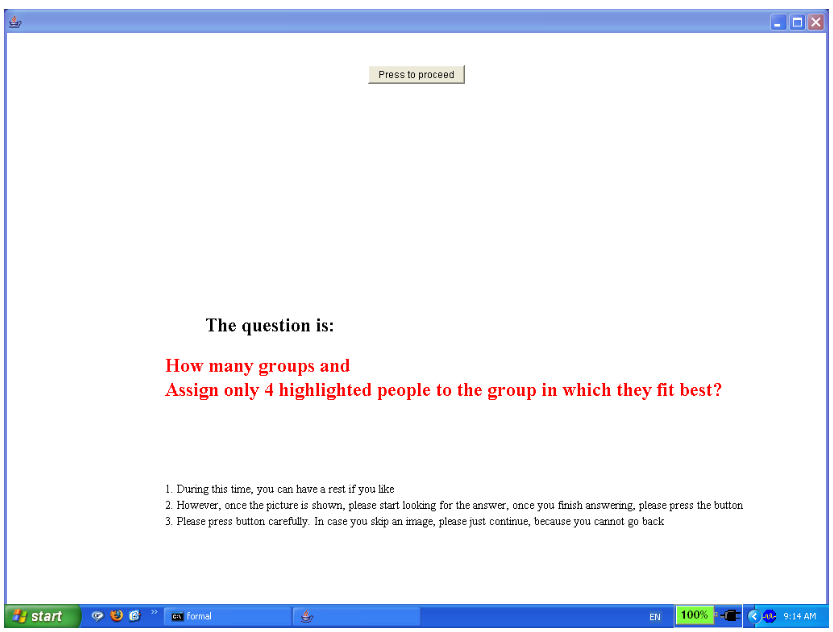


Figure 10: A question screen of the online system

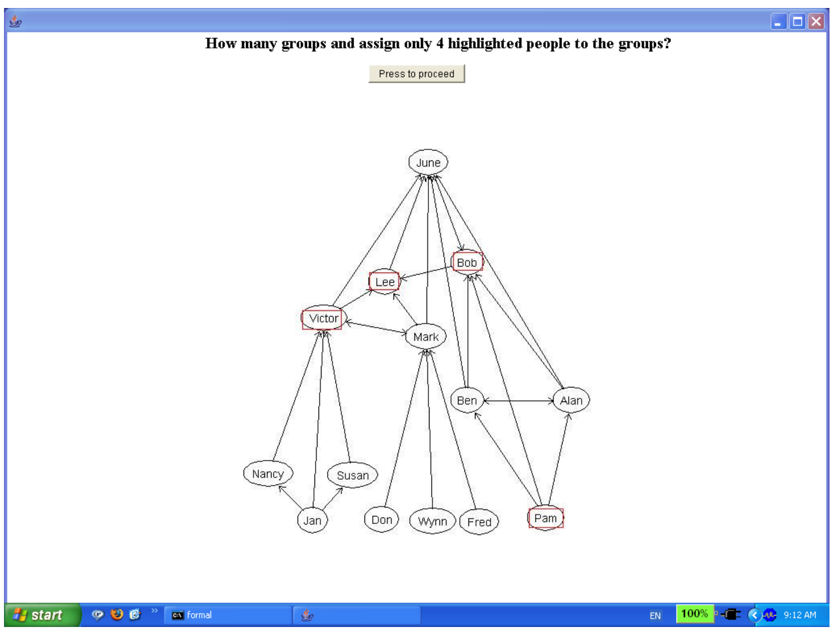
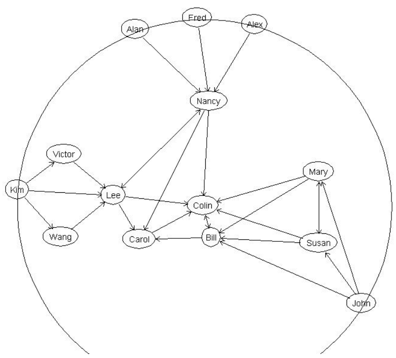
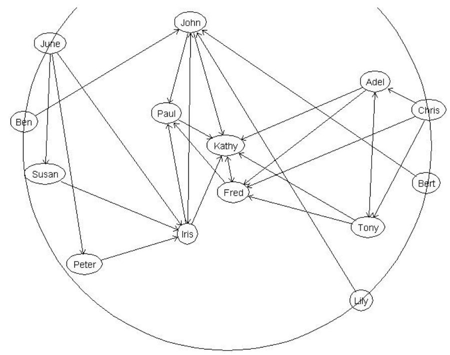


Figure 11: A drawing screen of the online system

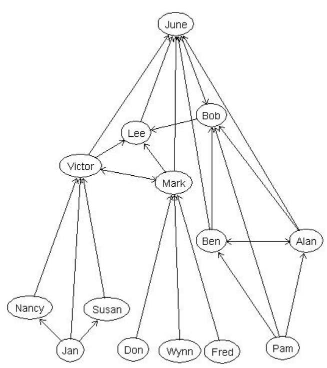
4 Sociogram Examples

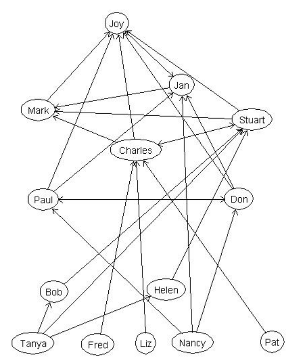
Minimum-crossing	Many-crossing





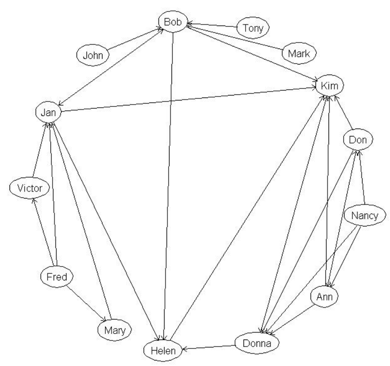
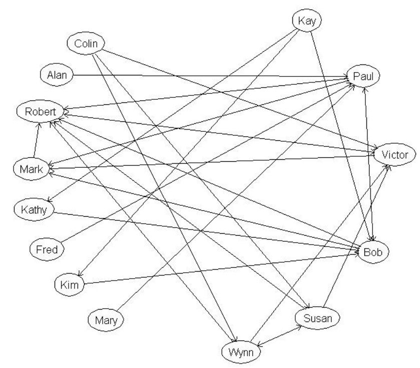
Radial layout



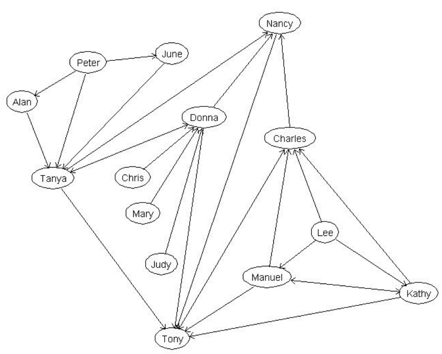
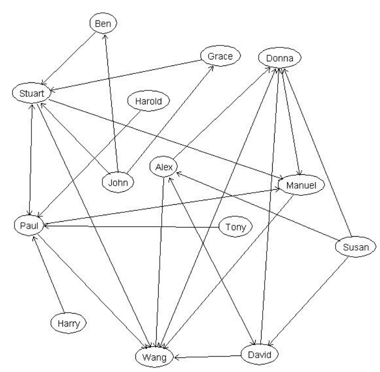


Hierarchical layout

Table 4: Sociograms for the advice network used in the study (1)

Minimum-crossing	Many-crossing
	

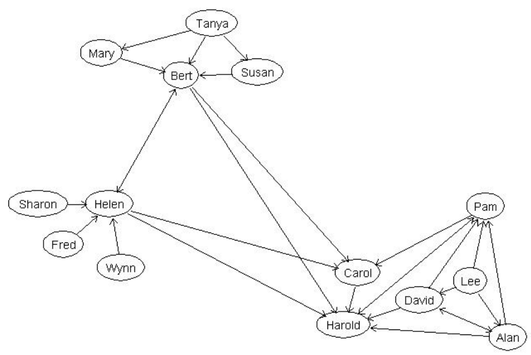
Circular layout

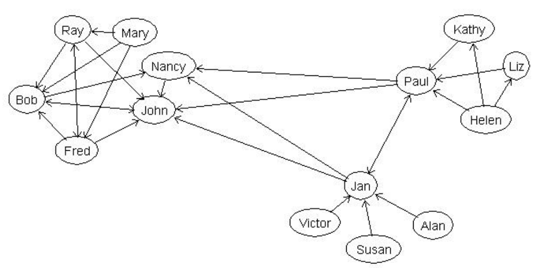
Free layout

Table 5: Sociograms for the advice network used in the study (2)

Group layout



Minimum-crossing



Many-crossing

Table 6: Sociograms for the advice network used in the study (3)