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

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Abstract

This paper describes a within-subjects experiment. In this experiment, the effects of different spatial layouts on human sociogram perception are examined. We compare the relative effectiveness of five sociogram drawing conventions in communicating underlying network substance, based on user task performance and personal preference. We also explore the impact of edge crossings, a widely accepted readability aesthetic. Both objective performance and subjective questionnaire measures are employed in the study. Subjective data are gathered based on the methodology of Purchase et al. [70], while objective data are collected through an online system.

We found that 1) both edge crossings and drawing conventions pose significant effects on user preference and task performance of finding groups, but neither has much impact on the perception of actor status. On the other hand, node positioning and angular resolution may be more important in perceiving actor status. In visualizing social networks, it is important to note that the techniques that are highly preferred by users do not necessarily lead to best task performance. 2) subjects have a strong preference of 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 and hypotheses about human reading behavior are proposed.
1 Introduction

A social network [87, 88] 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 of 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 explore and understand network structural characteristics, and to communicate specific information about the network to others [33, 16].

![Figure 1: Advice network formed by an auditing team. Courtesy of Krackhardt (from [53], Figure 9.2). Ellipses represent managers; diamonds represent staff auditors and boxes represent secretaries. A line from Donna to Nancy indicates that Donna seeks advice from Nancy.](image)

Clearly, a network can be visualized in many different ways [7, p. 100]. When a social network is mapped to a sociogram, what matters is relationship patterns, not the physical positioning of nodes [79, p. 64]. Many network visualization programs such as Pajek [3] and KrackPlot [52] typically use for example, variants of the Spring Embedder [24], or multidimensional scaling [55] to compute node positions [13]. However, the landmark study by McGrath et al. [59] revealed
that the spatial layout of nodes in a sociogram does affect human perception of social network characteristics, such as the existence of subgroups, the social positions of actors, although these characteristics are purely determined by the intrinsic network structure. The finding is significant because it indicates that people may perceive differently when a network is drawn differently. In other words, different drawings of the identical underlying network are likely to convey different, even conflicting information to humans.

Unfortunately, due to the diversity of network structural characteristics, probably there is no single best arrangement of nodes existing to communicate all the network information effectively at once [59]. Consequently, sociograms have been used to highlight one or two aspects of network structure, or to show a general pattern of connections without any specific highlights. Many techniques have been proposed. For example, hierarchical layout [13], which is aimed to convey a particular piece of network information about actor status effectively (more details later in section 2.2).

Although the usage of sociograms in social network analysis can be traced back to as early as 1930s by Moreno [66], effectiveness of their usage has not been received sufficient attention, considering their popularity and importance [60]. When we talk about effectiveness, there are two issues involved: readability and communication, although it is well known that there is no clear dividing line in between.

Readability can be affected by not only intrinsic network characteristics [38], but also layout. Among many factors, edge crossings has been widely accepted a major aesthetic affecting the ease of reading. Moreno [66, p. 141] suggested that edge crossings should be avoided in order to construct a “good” sociogram. In her pioneering work of a user study [68], Purchase compared the relative effects of five aesthetic criteria (bends, crossings, angles, orthogonality and symmetry) on user task performance, and concluded that edge crossings had the greatest impact on human graph understanding. Subsequently the aesthetic of edge crossings was validated on UML diagrams [70].

The remark of Purchase et al. in [70] that it is not necessary that findings based on domain-independent abstract graphs can apply to domain-specific diagrams motivates this paper. We are not aware of any previous user studies in examining the impact of edge crossings on the perception of social networks when domain-specific tasks are performed.

The second effectiveness issue is communication. Good readability does not necessarily lead to effective communication of the underlying network substance. In visualizing a social network, it is the effective communication of network information that is the most important, while enhanced ease of reading can facilitate the communication process [11]. A well designed sociogram should communicate exactly the same piece of information as what is intended to convey, both qualitatively and quantitatively [11]. The arbitrary visual presentation of the network may end up with a visual ‘mystery’ [84] allowing many different interpretations, or even worse, communicating false information [11]. This is because when interpreting sociograms, viewers bring a wealth of their own perception conventions (as shown in this study) and prior knowledge about
graphical representations [57] into this process. This suggests that social network interpretation can be much more sensitive to the spatial arrangement of elements in a sociogram than understanding other types of diagrams such as UML and ER diagrams. As a result, extra caution and effort should be taken to make sure that any misleading and false interpretations are avoided.

In the first attempt to formalize social network visualization, Brandes et al. [11] propose that a visualization process can be divided into the three components: specify the substance to be communicated (network substance), define a mapping from the substance to the corresponding graphical features (graphical design), and produce algorithms to realize the design (algorithm realization). Brandes et al. argue that an effective visualization should explicitly and sufficiently address the three components at the same time. It is also demonstrated in subsequent research [11, 12, 13] that the formalized three-component approach does reveal substantial network substance from a designer point of view. However, the question still remains: when we propose a new or adopt an existing sociogram constructing technique, how confident are we that viewers perceive exactly what is intended? What is more, since the visualization process is expensive, it is always desirable if the visualization technique used can convey other network information as much as possible, and prevent conveying any misleading or false information at the same time.

Surprisingly, although a considerable amount of network visualization software and techniques have been proposed in the literature [33], their success and usefulness in communicating the substantive content of the underlying network is typically judged based on either general aesthetics, personal intuitions, or some commonly used methods (such as circular layout) [13, 57, 59]. Very little empirical evidence is available to support their effectiveness in communicating network structural features to humans [60].

To address the above questions, we conducted a user study. In this study, we compared the communication effectiveness of five sociogram drawing conventions, and investigated the impact of edge crossings under each convention, based on quantitative data from user preference, usability acceptance and task performance and qualitative data from questionnaire. The aims of the study were:

1. To understand how a particular visualization technique, or a sociogram drawing convention can affect human sociogram perceptions.

2. To investigate the impact of edge crossings under each convention.

3. To propose a set of preliminary recommendations for sociogram design. Design guidelines generated on empirical basis should be more beneficial in facilitating human understanding.

Our long-time goal is to gain some new insights on how people perceive and interact with visual diagrams.

The findings from obtained quantitative and questionnaire data have been reported in [45] and [46]. This paper is the expanded version. The remainder
of the paper is organized as follows. In section 2, related work is reviewed with a focus on graph readability studies and sociogram perception studies. We also briefly introduce five social network visualization conventions, and the aesthetic of edge crossings. In section 3, the detailed experiment is presented. The research hypotheses are also formulated in this section as well. We report the main results and findings of the experiment based on both quantitative data in section 4 and qualitative data in section 5, followed by general discussion in section 6. We discuss the limitations of our findings, and envision some directions for future work in section 7. And finally section 8 concludes.

2 Background

2.1 Related Work

In this section, we selectively review related work with a focus on sociogram perception and graph readability studies.

2.1.1 Sociogram Perception Studies

McGrath, Blythe and Krackhardt have conducted a series of significant user studies in this area, investigating the spatial layout impact on human perceptions at different structure levels. First, at the individual level, McGrath et al. [59] administered the first study investigating how layout affects human sociogram perception. Five different drawings of a network were used. In each of these drawings, the spatial arrangement varied in Euclidean distance between two nodes and nodes to the center of the drawing. Subjects were asked to identify the number of groups present in the network and actor status in terms of prominence and bridging. It was found that both network structure and spatial arrangement of nodes influenced the understanding of network structural features [59].

Further at the group level, McGrath et al. [58] conducted a user study suggesting that the perception of network groupings can be significantly affected by visual clusters appearing in a sociogram. They proposed the ‘first principle’ in designing sociograms, which is “adjacent nodes must be placed near to each other if possible, and Euclidean distance should be correlated with path distance” [58].

More recently, at the overall network level, in a large study in which 133 subjects were involved, McGrath et al. [57] investigated:

1. The difference in effectiveness when a sociogram is drawn to convey a specific aspect of the underlying network, and drawn to conform to general graph drawing aesthetics.

2. The impact of motion and layout on human perceptions of status changes of an actor.
3. The effect of different layouts on the overall understanding of the underlying network.

McGrath et al. [57] used two different layouts: spatial hierarchy and spatial centrality and found the following:

1. The difference of layout formats did not have a significant effect on user performance.
2. The introduction of motion with hierarchical layout significantly increased perception accuracy of network changes.
3. The prior knowledge and experience of subjects with a particular layout could affect their overall network interpretations.

2.1.2 Graph Readability Studies

In a project investigating the effects of aesthetics and algorithms on graph perception, Purchase et al. conducted a number of empirical studies both in abstract graph and application domains. Among them, Purchase et al. [69] first validated three graph drawing aesthetics (crossings, bends and symmetry) using paper-based experiments, and revealed that these layout aesthetics do affect human graph understanding. Then in an online study, Purchase [68] considered the five aesthetic criteria consisting of symmetry, edge crossings, angular resolution, and orthogonality, and demonstrated that minimizing crossings was overwhelmingly beneficial in understanding graph structure; edge crossings was “by far the most important aesthetic”.

Also they extended their approaches into the application domain of UML diagrams, and evaluated the effect of individual aesthetics on user preferences [70]. Purchase at al. concluded in [70] that a visualization generated conforming to generic readability aesthetics is not necessarily effective in conveying domain specific information.

Further, in an experiment which examined several aesthetics within the same set of computer-generated diagrams, Ware et al. [86] suggested and demonstrated that good path-continuity has a positive impact, and found that what matters is the crossings on the shortest paths for shortest-path searching tasks. Another notable contribution in this study is the introduction of new evaluation methodology which enables investigators to do cognitive cost assessment and is applicable to similar perception problems.

Instead of aesthetics, Ghoniem et al. [38] compared readability effects of two visual representations (node-edge and matrix-based representations of abstract graphs) and graph intrinsic properties (size and density), based on seven generic tasks. They found that readability effects of the two representations varied with size and density of graphs for different types of tasks. In particular, node-edge diagrams are more suitable for small graphs while matrices achieve better readability for large or dense graphs. And more significantly, they proposed a generic task list and methods for the evaluations of the similar type, and recommendations in choosing effective graph representations.
2.2 Sociogram Drawing Conventions

Various sociogram drawing techniques have been proposed to highlight and communicate one particular aspect of network structure, and conform to aesthetic criteria to improve readability. Of our particular interest are the following five sociogram drawing conventions. For examples, see Figure 16 in appendix D.

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 [79].

2.2.2 Radial Layout

Radial layout was firstly proposed by Northway [67] as a target sociogram (Figure 2). Nodes are laid inside concentric circles whose radii increase as the status levels of nodes decrease, with the most central nodes in the center of the diagram. The ordering of nodes in the circles is manually determined so that the length of the lines connecting them are short. Brandes et al. [12] suggested a similar approach which places nodes on the circumference of circles in a way that their distances from the center exactly reflect their centrality levels, and the nodes on the circles are arranged by a three-phase energy-based layout model to make the final layout readable [12] (e.g., Figure 3). Note that in Figure 3, the additional circles are visible for illustrating different centrality levels, instead of a separate tabular presentation [12].

2.2.3 Hierarchical Layout

To aid people in exploring network structure and communicating information about actor status, Brandes et al. [13] proposed a new approach, an explanatory layout model which directly maps the status scores of actors to the vertical coordinates of nodes; the horizontal positioning of nodes is ‘algorithmically’ computed such that the overall readability in the final visual network representation is achieved [13].

2.2.4 Group Layout

Group layout (for a review, see [34]) is used to display information about groupings. 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 any purpose of highlighting a particular network feature. Instead, sociograms are drawn based on general aesthetic principles so that the layout is readable. Many automatic graph drawing methods can be used for this purpose (see [21, 50]).
Figure 2: Target sociogram [67], where node status is defined by how often the node is chosen.

Figure 3: Radial layout of betweenness centrality. Courtesy of Brandes (from [12], Figure 7).

2.3 Edge Crossings

It is widely accepted that edge crossings in a node-edge diagram not only hide important information from the viewers [21, 50, 68], but also make the viewer reluctant to approach the diagram in the first place [70]. Subsequently, edge crossings has been adopted as one of aesthetical criteria and poses significant scientific challenges in constructing visually pleasing and readable node-edge diagrams (e.g., [21, 30, 75]). Moreno, who first systematically introduced ‘sociogram’ into social network analysis [79, p. 9], stated, “The fewer the number of lines crossing, the better the sociogram.” [66, p. 141]. Bertin [7] further made it clear that,

“The simplest, most efficient construction (node-edge diagram: authors’ note) is one which presents the fewest meaningless intersec-
tions, while preserving the groupings, oppositions, or potential orders contained in the component . . . " [7, p. 271]

Although keeping the number of edge crossings minimum has long and widely been used as a general rule in producing diagrams, it is Purchase and her colleagues who first provided empirical evidence validating the aesthetic of edge crossings, and demonstrating its significance of negative impact on humans (e.g., [71, 68, 70]).

3 Experiment

It is important to note that, by investigating communication effectiveness, we mean that we have already had some knowledge about the network in advance. For example, who are important actors? how many groups are there in the network? Then the network is visualized using each of those drawing conventions to communicate our knowledge to others. We expect that people could perceive the same as we did. Effectiveness was measured in terms of response speed and response accuracy. Among different experimental conditions, if subjects performed a task “correctly” in a shorter time with one condition, then we would say that the condition was more effective in communication for that particular task. To have an overall understanding of the effects of drawing conventions and edge crossings, we also measured user crossings preference and usability acceptance for different tasks as well.

In addition, in both the sociogram perception and readability studies mentioned in section 2.1, either performance or preference was used as a major measurement. In our experiment, a questionnaire study was employed as a complementary approach to the quantitative measures [70]. The questionnaires were mainly about how the subjects read sociograms. By combining questionnaires with traditional performance and preference measures, we believe that the qualitative data derived from the questionnaires can help in gaining in-depth insights which otherwise is unlikely to obtain by just looking into static and silent quantitative data. In particular, questionnaires were used in the study in order to:

1. Collect information about the background of subjects, their experience with node-edge diagrams.
2. Identify possible confounding factors.
3. Provide support for findings of quantitative data.
4. Help to find roots of problems which may not be obvious in quantitative data.
5. Gain insights on sociogram reading behavior.
3.1 Network measures used in this study

For this experiment, two main social network measures which are frequently used in network analysis [59, 33] 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 social status of an actor (see [87, 13]), and social groups (see [87, 34]). For example, status can be measured based on degree centrality, between centrality [32, 35], or Katz status score [49]. Grouping can be either demographic-based, ethnographic-based [58], or graph theoretical based (such as n-clique, relative density [64, 65]).

In this study, the Katz status score was used as the index of importance. Relative density was chosen for measuring groups. These measurements are considered because both, we believe, are close to the everyday-life notions in the context of the networks used. In particular, Katz status score is suitable for measuring status in directed graphs since the score considers not only “who chooses”, but also “how many choose” in determining status. For details, see [49]. 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 [77] and [64, 65].

3.2 Subjects

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

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

1. In communicating information about social networks, it is quite common in real world that sociogram viewers are novices [54].

2. Experienced sociogram readers likely already have knowledge about drawing conventions and edge crossings; therefore findings based on their responses can be biased.

3.3 Networks

Two networks were used. One was Krackhardt’s advice network [53]. The network has been used in [57] for the effectiveness comparisons of hierarchy and centrality layouts in conveying overall network information, and used as an example in [13] to develop the hierarchical approach. 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 (see group layout in Figure 16) in a sense that we discuss later in this section.

| Nancy  | Fred  | 0.02 |
|--------|-------|------|
| Donna  | Sharon| 0.02 |
| Manuel | Harold| 0.00 |
| Stuart | Wynn  | 0.00 |
| Charles| Susan | 0.00 |
| Kathy  | Bob   | 0.00 |
| Tanya  | Carol | 0.00 |

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

The Katz status scores [49] of the actors in the advice network 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 forth.

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

3.4 Sociograms

To investigate drawing convention effects, the same network was drawn using each of the five conventions described in section 2.2. To test the impact of edge crossings, two sociograms of the same network were drawn for each convention: one had a minimum number of edge crossings, the other had many crossings. Therefore, for the advice network, a total of ten sociograms were obtained (see Figure 16 in appendix D). Note that in the radial sociograms, 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 convention drawing with minimum crossings and a free convention drawing with many crossings were given.

All 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 the real world social network perspective [59]. 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 rate them according to their importance levels; and

(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 one actor should not belong to more than one group, and one group should not include only one actor. In formal tests, the same four nodes (actors) across all drawings were highlighted with red rectangles.

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 in one page (paper), and all the six minimum-crossing drawings were shown in 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 ten advice network drawings being shown in one page, subjects needed to choose three drawings that they least preferred and three drawings that they most preferred for their overall usability. Then they ranked the 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 sociogram features that they think may influence their graph perceptions. The second questionnaire asked about their thoughts about the drawing conventions and edge crossings. Copies are in appendices A and B.

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 record the response speed of subjects. 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. Therefore, while the accuracy for the two sub-tasks were measured separately, the response time logged was for the two sub-tasks in total. The examples of screen shots are in appendix C.

3.7 Design
The study employed a within-subjects design. For the online tasks, 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 random. Subjects were told they could have breaks during the question viewing periods if they wished. They all had a short break after finishing the online tasks to refresh their memory. This is particularly important and necessary for eliminating possible biases for the following rating tasks, since the subjects might not see all the drawings to be rated during the online tasks.

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.

It is worth to mention that, during the tutorial time, subjects were not directly given the strict definitions of Katz status score and social group. Otherwise, we are able to only measure readability and not communication effectiveness. On the other hand, as a result of this, subjects may use different strategies and task criteria to accomplish tasks; this can be seen from the responses of subjects in section 5. This is one of major reasons why within-subjects design was employed in the study. It is reasonable to assume that, reading strategies and task criteria used are consistent individually while they may differ across individuals when performing tasks.

3.7.1 Pilot Study
A pilot study had been conducted with another four subjects who did not have any social network background to check our methodology. They demonstrated
that they quickly understood the questions and felt comfortable with the experiment. They related the visual network representations with their daily social experiences when performing tasks.

Their verbal comments suggested that the tasks used were visually challenging but not overwhelmingly difficult. However, they had slightly different criteria in dividing actors into groups. To make the experiment controllable, we modified the group task - we added a condition as described in section 3.5.

### 3.7.2 Hypotheses

Based on the prior research mentioned in section 2, we predict that:

- **H 1.** Drawing conventions have a significant impact on user responses in terms of crossings preference, usability acceptance, and task performance.

- **H 2.** Edge crossings have a significant effect on user responses in terms of crossings preference, usability acceptance, and task performance.

We also have one more specific hypothesis to be tested:

- **H 3.** Group layout is more effective than others to convey group information; hierarchial and radial layouts are more effective than others to convey actor social status.

This hypothesis was developed based on the following considerations. First, it has been reported [59] that circular layout did not perform well in perceiving either node centrality or groupings. Second, radial and hierarchical layouts were originally proposed to increase communication effectiveness. Both layouts explicitly map the structural centrality or status of an actor to the geometric centrality or hierarchy of a node in the resulting sociogram, and maintain overall ease of readability at the same time [13, 12]. In [57], it was demonstrated that hierarchical layout had some advantages over centrality layout when motion was introduced for communicating status changes of an actor. Third, there are a great variety of automatic free layout algorithms available [21]; only a few of these, mostly those derived from multidimensional scaling [55] and the Spring Embedder [24], have been used for social networks. These methods sometimes highlight social status and/or grouping [34, 12]. However, sometimes they do not. Further, the results of these methods can be misleading [12], since the mathematically optimum layout may not reflect the socially significant groups or central actors. Fourth, group layout arranges nodes in the way which is consistent with the ‘first principle’ of McGrath et al. [58] mentioned in section 2.1, and has a long history in practice (see [34, 66]). According to Larkin and Simon [56], grouping relevant elements together in close proximity to each other facilitates perceptual processes by reducing visual searches, thus making pattern recognition easier.

In addition, we also check whether a drawing is effective in conveying other information. For example, if a convention is aimed for status, then we would
like to see whether it can also convey information about grouping correctly, and vice versa. However this is exploratory by nature, therefore there is no formal hypotheses made for this issue.

3.8 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. The drawings used for practice were quite different from the ones used in formal tests, since the practice in this study was only for familiarization with the procedure and system, not for subjects to get experienced with sociogram reading.

Once ready to start, subjects indicated to the experimenter, and started running the online system performing tasks formally. After the online reading tasks there was a short break, then they proceeded with the rating tasks, and 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 about the experiment. The whole session took about 60 minutes on average.

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 differences, these data have been omitted in our analysis. For simplicity, we use C, R, G, H, and F to represent circular, radial, group, hierarchical and free drawing conventions, respectively. We use P for minimum-crossing drawing, and C for many-crossing drawing. For example, CP denotes circular minimum-crossing drawing; CC denotes circular many-crossing drawing, and so on.

Thus, the independent variables were drawing convention and the number of edge crossings. The control variables were the importance task and the group task (note that the online tasks, rating tasks and questionnaires described in section 3.5 are irrelevant).

The dependent variables included response time and response accuracy for effectiveness, as well as crossings preference ratings, usability ratings, and overall ratings. Response times were recorded by the online system, while other variables were collected based on the responses of subjects on the answer sheets provided.

The quantitative data produced were analyzed using various statistical methods and presented in the following subsections. Throughout our analysis, the significant level of 0.05 was used, unless otherwise stated.
In particular, for usability acceptance and response time analysis, to examine edge crossings impact, we compared each pair of drawings for each convention, and all minimum-crossing drawings with all many-crossing drawings. To examine drawing conventions effect, we performed statistical tests on all minimum-crossing, all many-crossing, and all ten drawings (only this was reported though), respectively. If there was a significant difference among all minimum-crossing drawings, then the further pairwise comparisons would be conducted. We did not do pairwise comparisons for all many-crossing drawings, since the negative effect of edge crossings was evident throughout the analysis.

4.1 User Preference Data

4.1.1 Usability Acceptance

The usability rating scale data of subjects are illustrated in Figures 4 and 5 and analyzed using Analysis of Variance (ANOVA) (with Fisher’s PLSD, for pairwise comparisons).

For importance tasks, the minimum-crossing drawing was generally rated higher than the many-crossing one for each convention. There was a significant crossings effect between all minimum-crossing and all many-crossing drawings ($p = 0.00$). Also there was a significant conventions effect among all drawings ($p = 0.00$). The pairwise comparisons among all minimum-crossing drawings revealed that the user acceptance for CP was significantly lower than GP, HP and FP, respectively; the user acceptance for RP was significantly lower than CP.
Table 2: Pre- and post-debriefing scores for importance

|     | 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 3: Pre- and post-debriefing scores for groups (only data with significant changes are shown)

|     | 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 |

Figure 6: Mean importance preference scores

Figure 7: Mean group preference scores
and HP, respectively. Furthermore, paired t tests showed that after debriefing, the drawings of both hierarchical and radial conventions were rated significantly higher (see Table 2). In particular, the mean scores of the hierarchical convention pair were higher than all others in both pre- and post-debriefing ratings, suggesting that the edge crossing criterion was perceived as less important than the positioning of nodes for importance tasks.

For group tasks, GC and GP were rated much higher than others; in fact the others were perceived as having little usefulness. Statistical analysis revealed a significant crossings effect for each pair of drawings for all conventions \((p = 0.00)\) except the group convention. Also, conventions produced a significant difference among all drawings \((p = 0.00)\). Pairwise comparisons among all minimum-crossing drawings showed that all pairs were significantly different each except the pair of HP and FP. In the data of post-debriefing ratings, there was a significant change for RP, CC, FC and HC, respectively (see Table 3).

4.1.2 Crossings Preference

As can be seen from Figures 6 and 7, generally, subjects preferred the minimum-crossing drawing more for each convention. The \(1\)-sample t tests against the hypothesized mean \(= 0\) revealed that for all conventions except the group convention, the preference of subjects for the minimum-crossing drawings over the corresponding many-crossing drawings was statistically significant \((p < 0.01)\).

The paired t tests revealed that there were no significant changes between the pre- and post-debriefing ratings, although the post-debriefing preferences were generally weaker than pre-debriefing preferences for both importance and group tasks. In particular, after debriefing, subjects preferred many-crossing group drawing slightly more than its minimum-crossing counterpart instead.

4.1.3 Overall Usability Ranking

![Figure 8: Overall usability values](image)

The ranking values of subjects for each drawing were summed as a weighted value, and weighted values for all drawings are shown in Figure 8. It can be seen that generally, the many-crossing drawings were less preferred except GC, which
was ranked 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 having little overall practical utility.

4.2 User Performance Data

4.2.1 Response Time

The response time data of subjects are illustrated in Figures 9 and 10 and analyzed using the non-parametric method of Kruskal-Wallis [39].

For importance tasks, subjects spent shorter time with the minimum-crossing drawing than the many-crossing drawing for each convention in general. Among all minimum-crossing drawings, the shortest time was spent with GP, followed by CP, HP, RP, and finally FP. However, statistical tests revealed that these differences of response time were not statistically significant in terms of the effect of either edge crossings or drawing conventions.

For group tasks, following a similar pattern, again shorter time was spent with the minimum-crossing drawing than the many-crossing one for each convention. Among all minimum-crossing drawings, the shortest time was spent with GP, followed by RP, CP, HP, and finally FP. Analysis showed that there was a significant crossings effect between the minimum-crossing and many-crossing pair of circular convention \( (p = 0.012) \), and between all minimum-crossing and all many-crossing drawings \( (p = 0.021) \), and a significant conventions difference
among all drawings ($p = 0.000$). Pairwise comparisons showed that subjects spent significantly shorter time with GP than all the others at the level of 0.01.

4.2.2 Reported Group Number and Member Group Assignment

![Figure 11: Distributions of reported group number](image)

Figure 11 illustrates the distribution of the reported group number for each drawing. As can be seen, GP had largest proportion of subjects (82.4%) reporting the number of groups present in the network “correctly” (three as expected). Considering the distribution shapes in Figure 11, it is clear that, CC had a much flatter distribution, suggesting that it failed to convey the group information consistently to the subjects [59]. An analysis of variance of the reported group number for all drawings showed there was a difference with significance at the level of 0.066.

Also, at the dyad level, the member group assignment task was to investigate edge crossings and conventions impact on the perception of the co-memberships of actors. As can be seen from Figure 12, a relatively larger proportion of subjects performed this task correctly on the minimum-crossing drawing than on the many-crossing drawing for each convention except free convention. Among all minimum-crossing drawings, GP yielded the highest correctness rate (76.5%).

4.2.3 Identifying Most Important Actors

Figure 13 shows the weighted values for all drawings. The weighted value is to measure the overall effectiveness of a drawing in conveying information about importance, and calculated in the following way. First we gave an index of 5 to the most important actor, 2 to the second and 1 to the third; then the productions of indices and corresponding correctness percentages were summed as a weighted value for each drawing. It can be clearly seen, surprisingly, that
4.3 Summary and Discussion

Analysis of the quantitative data reveals that our three hypotheses are only partly confirmed.

There is strong evidence that edge crossings contributed to the significant differences in crossings preference, usability acceptance, and group task performance, except importance task performance. Edge crossings affected not only the ease of reading, but also the understanding of network structures.

With respect to drawing conventions, there were significant conventions effects on usability acceptance and group task performance. Again, no apparent evidence was detected that there was a significant conventions impact on user importance task performance.

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

Quite surprisingly, subjects were overwhelmingly in favor of hierarchical convention for importance tasks; they spent relatively short time with HP, but obtained the lowest correctness rate among all minimum-crossing drawings. On the other hand, FC obtained the highest correctness rate, but relatively long time was spent with it. We realized that some subjects had complained in questionnaires (see below) and verbally that in some drawings, edges were incident to nodes too closely to clearly identify arrow directions. Visual inspections revealed that indeed, free convention drawings had very good angular resolution, while hierarchical convention made angular resolution relatively low, where edges had to be crowded on either side of nodes. In addition, subjects spent longer time with FC, which might actually allow them to have better chance to understand network structure better.

To reiterate, for importance tasks, there is no clear consistent patterns appearing in Figures 13 and 9, in terms of either edge crossings or drawing conventions. Subjects generally performed better when they took longer time. Taking into account the responses of subjects in questionnaires (see below), we conjecture that only those tasks which are closely related to edges and involve intensive path or edge tracing can be significantly affected, such as finding groupings. On the other hand, for communicating information about actor status, the node positioning and angular resolution in a sociogram may be more important, compared to reducing the number of edge crossings and spatial arrangement in terms of drawing conventions.

5 Qualitative Results

Qualitative data collected from the responses of subjects to the rating tasks and questionnaires were combined and are presented in this section. Throughout the discussion, we relate qualitative questionnaire results with quantitative findings, and discuss their implications for sociogram design. Note that comments of subjects can only be interpreted at the perception level. They can be used as complementary evidence to explain and reinforce our observations. Completely relying on the comments to explain the objective results can be misleading.

5.1 Edge Crossings Effects

Our quantitative results showed that edge crossings had significant effects on crossings preference, usability acceptance, and group task performance. Nearly 100% of subjects indicated that drawings with fewer crossings are desirable and easy to read. They commented drawings with many crossings “hard to read”, “confusing”, etc.

However, no evident evidence was found suggesting that edge crossings posed a significant impact on importance tasks performance. One reason for this may be that in perceiving importance, the main focus of the viewer was on identifying the outgoing and incoming arrows of a node. This could be done
locally by just looking around the node; hence edge crossings had little impact. The comments of subjects lent some support for this explanation. For example, “In finding important people, maybe location is more important than crossings”; “For finding who is important, just look upon the arrows, but a more traceable graph is helpful”. However, most subjects disliked edge crossings. “Crossings matter when finding which nodes are important in a directed graph, and edges with fewer crossings can reveal relationships easily”; “Crossings matter when counting the number of groups”.

5.2 Drawing Conventions Effects

5.2.1 Circular Layout
Circular layout had moderate task performance, but was least accepted in usability. Indeed, it treats all nodes equally by placing them in a circle without any particular priority, thus making network structure features hard to discern. User comments include “I hate meaningless circular layout”; “nodes in the same circle look like they are equally important”; “it is frustrating following long edges from one side to the other side to find groups”.

5.2.2 Radial Layout
Radial layout had moderate user ratings and task performance. Although there is a big visible circle around the diagram, very few subjects realized nodes were actually arranged radially. Since the reading habit of the subjects recruited is left-to-right and top-to-bottom, adding a big circle around the diagram did not necessarily make them read radially. Providing clear visual hints such as adding circles at each level could be helpful. But this also increases visual complexity, and may confuse viewers. Some subjects made comments such as “what is the outer circle for? I do not think it was necessary”; “it is better to have circles visible if radial layout is to be used”; “it is good to put the most important node in the center, but it is crowded with others”.

5.2.3 Group Layout
Group layout was rated high for group and overall usability, and moderate for importance usability. It also had very high user performance for group tasks, and moderate performance for importance tasks. User comments include “groups are already spatially separated”; “very clear overall structure”; “good for grouping”; “relationships are clear”; “it would be better if putting the group having the most important person on the top”.

One finding worth mentioning here is related to the impact of edge crossings on the task of finding groups. Some subjects claimed that, for group layout, crossing edges within groups gives a stronger sense that nodes are linked closely (see Figure 14). Further, since edges within a group are naturally dense, by crossing edges, it is easier to identify relationship patterns between the nodes.
For example, “Crossings probably do not matter when nodes belonging to different clusters have already been separated”; “Crossings are helpful when there is a pattern”. This indicates that the introduction of edge crossings into a sociogram may hardly have any negative impact for communicating groupings. This is consistent with the quantitative results (see section 4 for details).

![Figure 14](image)

Figure 14: It is argued that drawing (b) gives a stronger sense of group, and is easier to find relationship patterns than drawing (a).

### 5.2.4 Free layout

Free layout had moderate user ratings for importance tasks, and low ratings and performance for group tasks. Some subjects commented that nodes seemed “not organized”, “unordered, making grouping difficult”; “some edges were unnecessary long”; “each time I look at the diagram, it seems there are different ways of grouping”; “it is easy to think Nancy is the most important because she is placed on the topright corner, but clearly Tony is more important; however he is easy to miss because he is placed on the bottom”; “it is easy to identify important nodes”.

### 5.2.5 Hierarchical layout

This layout was most preferred for importance tasks, but had low ratings and performance for group tasks. Comments include “I prefer tree-like layout”; “it is good to arrange arrows pointing the same direction”; “it is easy to see the most important people on the top”; “the directions of edges attached to the top node are hard to tell to me”; “long edges make some nodes in the same group separate”.

5.3 Visual Factors in Sociogram Reading

The responses of subjects to the questionnaires were categorized and presented as follows:

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 relations and spatial 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 responded like “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 your understanding?

Based on the responses of subjects, nodes and edges in a sociogram should be carefully organized and treated individually according to their individual roles in the network and visualization purposes. For example: nodes should not be evenly distributed; distance between nodes should reflect their relationship; 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 groupings?

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, nodes that are intensively linked 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.

5.4 Summary

The analysis of the responses of subjects to questionnaires and interviews revealed that subjects had perception conventions in reading sociograms. The subjects had a strong preference of 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 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.

With regard to sociogram reading behavior, subjects tended to consider those nodes in their central attentions high in importance. Due to the close relationship between visual attention and eye movements [73, p. 375] [85, p. 154], four hypotheses were made based on the comments of subjects which need confirmation with specifically designed experiments:

1. When looking at a diagram, the first couple of fixations are on the top and central areas, and overall more time is spent on these areas than the other peripheral areas.

2. When looking at a diagram, the first couple of fixations are on sparse areas, and overall less time is spent on sparse areas than dense areas where nodes and edges are crowded.

3. However, their normal eye movement patterns can be changed and guided by introducing visual hints into diagrams. For example, circles in radial layout.

4. There are significantly more edge searching eye movements for group tasks than for importance tasks. For importance tasks, eye movements are mainly around nodes.

There are many sets of aesthetic rules available for drawing graphs. In [80, 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 [4, 21, 70, 27]. More specifically, Brandes et al. [11, 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 literature review and opinions of experts. In this study, we derived a set of sociogram design recommendations based on empirical evidence and listed them below:

1. “Do not” rules
   (a) Do not distribute nodes randomly
   (b) Do not treat nodes (and edges) equally or distribute nodes evenly [19, 51, 2]
   (c) Do not cross edges haphazardly

2. Task-independent rules
   (a) Reduce crossing number [15, 5, 62, 41]
   (b) Keep edges shorter and nodes adjacent when the underlying relationships are closer [24, 55, 36]
(c) Arrange arrows to point to the same direction [47, 41]
(d) Provide additional visual hints when necessary

3. Rules for group tasks

(a) Cluster nodes which belong to the same group [26, 61, 9]
(b) Separate groups spatially [78, 64, 65, 48, 43] or by adding boundaries [81]
(c) Cross edges when edges are dense in a group [6]

4. Rules for importance tasks

(a) Highlight status hierarchy using hierarchical [13, 23, 63] or radial layout [12, 1, 25, 83, 74]
(b) Increase angular resolution [37, 22, 14]
(c) Put the most important nodes on the top or in the center [89]
(d) Highlight important nodes, by using color, size, etc. [8, 42, 29, 20]
(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) suitable alongside some of the rules above. For more information, the reader is referred to proceedings of annual conferences such as Graph Drawing and Information Visualization, and books [80, 21, 50]. In addition, in drawing sociograms and designing algorithms, it is important to have clear priorities between these rules in advance. Priority can be built based on the purposes of the designer, empirical studies [68, 70], general discussions [28], or theoretical considerations [80]. Here we took the theoretical approach of Sugiyama (for details, see [80, p. 15-16]). We divided the rules into four groups and ordered them from high to low in priority as follows: “Do not” rules, task-independent rules, task-dependent rules (group tasks rules and importance tasks rules). In each of the four groups, rules were also ordered from first to last as they are in the list above.

The eye movements hypotheses and recommendations we proposed should be interpreted within the experimental settings. To be more specific, the hypotheses and recommendation list were drawn mainly based on the responses of subjects for performing importance and group tasks. They need confirmation with further studies and refinement as our understanding about human sociogram perceptions improves. Extra care should be taken in generalization.

6 General Discussion

There are three themes covered by the study above. We discuss each of them in detail as follows.
Firstly, we provide additional empirical evidence for the prior finding that human sociogram perception can be affected by not only the intrinsic network structural features, but also spatial layout of the sociogram [59].

**Human sociogram perception conventions, visual drawing features and network structural characteristics all have their roles in making sense of network data.** According to McGrath et al. [59], the Euclidean distance of a node to the center of the sociogram has negative impact on the perceived node status; this was supported by our qualitative results. It is reasonable to assume that the impact of the distance between the node and the center is attributable to the perception conventions of subjects including importance tendencies (for example, they tend to perceive nodes in the center as being more important) and preferences (for example, they prefer that important nodes are placed in the center). In our study, radial layout places important nodes in or near the center, thereby highlighting both their structural and spatial attributes (hierarchical layout has a similar effect). However, user performance with radial drawings was not significantly better than with other drawings, in terms of response speed and accuracy. Clearly, the structural features of a node and its Euclidean distance to the center are not the only factors in determining the perceived status. 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 structural features may all have their roles in understanding network structure.

The impact of perception conventions is not only limited, but also interacts with network characteristics. This study was not intended to, and did not reveal how much influence of the perception conventions had on the final decisions of subjects in determining groups and status. However, it is important to bear in mind that solely relying on spatial arrangements to convey network information can be at risk of failure. After all, groups and status are completely determined by the network structure. Not only is the influence limited, but also varies with the level of the significance of actor status and group patterns within the network [59]. In other words, there are interactions between the perception conventions and network structural features. Both ignorance and exaggeration of the influence can make quality communication difficult. Obviously, to a certain extent, it is the interference of the perception conventions that makes communications unpredictable. As a result, a good visualization should respect these perception conventions. When a sociogram is presented in a way which is inconsistent with the perception conventions of humans, although they are not necessarily a determining factor, it is reasonable to expect that degraded performance will occur. Also, further studies are needed to understand how these conventions work, so that we can find a way either to avoid the bias introduced [59], or take advantage of them in exchange of information.

Secondly, this study also extends the prior research with respect to two aspects. First, it examines and compares the relative effectiveness of the five sociogram drawing conventions. For group tasks, group layout [34, 64] was the only one that was perceived as high in usability, and had outstanding performance as well; this suggests its compelling superiority over other methods in
conveying group information.

For importance tasks, effectiveness of the radial layout \cite{25, 12} 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 radial layout is that the layout uses space effectively \cite{83}, thus scaling better with the size of networks than hierarchial layout. Further investigations are needed to fully take advantage of this layout. On the other hand, hierarchial layout \cite{13, 82, 23} was the one that was perceived as highest in usability and low in difficulty (response time), but actual response accuracy was not the best. Closer inspection reveals that angular resolution, a confounding factor, interfered with 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 angular resolution (e.g., \cite{37, 22, 14}); 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 a node. Further, in the resulting sociogram, while keeping angular resolution stable, both node size and position highlight social status. Although its actual effectiveness needs to be examined with further studies, according to ‘say it again’ principle \cite{76} and ‘friendly redundancy’ \cite{18}, we expect better user performance with this revised hierarchical layout. Alternatively, arrows can be indicated on the middle of edges. This avoids the interference of angular resolution in identifying arrows; however, the number of edge crossings needs to be minimized to make arrows clear.

It is important to make it clear that, a particular drawing convention, e.g., group layout, is relatively more effective in conveying group information than other conventions in general. It may not, however, be equally effective when a different group criterion is used. As we mentioned previously, the same network feature can be measured using many different approaches. For instance, importance can be measured according to betweenness centrality, or degree centrality of a node \cite{87, 32, 35}. However, in hierarchical layout, the betweenness measure does not have a spatial mapping as straightforward as 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 also can be found in \cite{59}.

Second, this study investigates the effect of the edge crossing criterion on sociogram perception using social network specific tasks. Consistent with prior research \cite{68, 70}, edge crossings are undesirable in drawing sociograms, and has significant negative impact on group tasks performance. However, there was no apparent edge crossings effect found for importance tasks. Cognitive process analysis and the comments of subjects revealed that the absence of significant impact may be because in performing importance tasks of the given context in this study, not much edge tracing was required (note that when a different importance criterion, such as betweenness centrality, is employed, edge tracing
can be involved). In other words, edge crossings matter only if intensive edge tracing is involved during tasks performance. This is new but should not come as a big surprise, since in prior research (e.g., [68, 86]), path searching tasks were mainly used in investigating edge crossings effects.

Thirdly, this study proposes design recommendations and hypotheses about graph reading behavior in terms of eye movements. These are derived based on the responses of subjects to questionnaires for performing importance and group tasks. These are rough and quite subjective. However, the design recommendations may serve as a starting point and preliminary basis for further developing design principles, which are urgently needed, while the hypotheses can be regarded as a first step toward a better understanding of how people read sociograms. It is important to note that these hypotheses and design recommendations were derived based on the responses of novices. It is feasible to imagine that, compared to experts, the reading behavior of novices can be more sensitive to spatial layout and their performances can be affected more by their perception conventions, thus leading to different eye movement patterns and layout preferences. In graph reading, visual search patterns can be influenced by both the visual features of the sociogram and prior knowledge of the related context. The former affects visual search in a bottom-up way while the latter influences 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, spatial arrangement of a sociogram 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 the novice viewers. With the increase of experience in reading and expertise in network knowledge, in the end, bottom-up impact can be overridden by top-down one.

In summary, all results add more evidence showing that there is no universal best representation existing for a network [59]. Whether a visualization is good or bad makes sense only when it is related to particular tasks and a targeted audience. As a general rule of thumb, in producing a sociogram, one should be aware that:

1. The influence of human perception conventions is limited, and may vary with the prominence level of the network feature in question appearing in the network, and the level of the knowledge expertise and reading experience of the viewer.

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

3. In deciding what layout should be used, the expertise of the audience and tasks should be taken into account.

In addition, the cost of making a particular spatial arrangement should be justified by the extent to which the layout facilitates understanding.
7 Limitations and Future Work

Any experiment has limitations [40, 68], so does this study. Therefore, the results from this study should be interpreted within the given experimental settings.

The limitations of the study have been identified as follows. They lie in two primary categories, and may be addressed in future investigations. Firstly, there are a couple of methodological limitations. One limit which is related to general human graphical perception experiments is that people are likely to behave differently from the way they do in their daily lives, when explicitly asked to perform online tasks in an experiment [17]. In addition, in the study, subjects responded to rating tasks and questionnaires after online tasks. As a result, their responses may not exactly reflect their actual perceptions in performing the online tasks. Insights drawn on these post-tasks data can be questionable.

Secondly, some specific limitations identified are related to experimental parameters. First, only a single small network was used in our analysis. This may limit the generality and scalability of the experimental results. Second, for the purposes of experimental design, during online tasks performance, subjects were allowed to view the sociograms only once. This may not fit in real world situations. Third, the subjects sample was small in size given the cognitive tasks used in the study. And they were all computer science students. Although we were limited by the resources available, it is always desirable to use real setting subjects to avoid any possible invalidity problems. Fourth, during the tests, subjects were told to perform tasks as quickly as possible without compromising accuracy. This is a rather ambiguous requirement, although it has been widely used in a variety of human studies. Individuals may perceive the requirement at different levels for time availability, thus affecting their reading behavior and task performance.

Despite these limitations, the significance of this study itself and its findings should not be overshadowed. The study set out to meet the urgent need for empirical evidence, to catch up with the progress made in social network visualization techniques [60]. 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. Investigate how different drawing conventions facilitate understanding for experts, and see how the reading behavior and performance change accordingly.

2. Replicate and confirm the findings obtained in the current study using networks of different sizes and contexts.

3. Using the insights gained in the study as a basis, further studies are worthwhile to understand how people interact with sociograms in general and how eye movement patterns are formed in particular based on real time protocols by using, for example, eye tracking (e.g., [44]) or think aloud (e.g., [72]) methods.
4. Human sociogram perception conventions were drawn mainly based on qualitative data in this study; these perception conventions need confirmation from quantitative evidence. For instance, to examine the impact of importance perception tendencies, we may systematically change the positions of both important and unimportant nodes [59], such as from top to bottom or from periphery to center, and see how perceived status of nodes change.

8 Conclusion

This study built on and extended the work of McGrath et al. [58, 59] on human sociogram interpretations. We compared relative effectiveness of five social network visualization conventions: radial, circular, group, hierarchical and free layouts, in conveying internal structure information at the individual and group levels. We also adopted the methodology of Purchase et al. [70] and investigated the impact of edge crossings when domain-specific tasks were used.

The results of this research add to the growing body of evidence that shows spatial layout of a social network visualization has an important role in communicating network substance effectively. This study, together with prior research [58, 59, 57], 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 effectiveness in communication from human understanding point of view. It should be noted that visualization techniques, which are highly preferred by users, do not necessarily always produce best task performance, as demonstrated in this study.

The findings from this study should be interpreted within the limitations of the given experimental settings. In this study we had only investigated the relative effectiveness of five ‘explanatory visualization’ [13] conventions and edge crossings impact under each convention, in communicating actor status and subgroup information to novice audience. 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 [16].

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APPENDICES

A 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 try to identify who is most important and how many groups?

5. When you answered questions, 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 help you to find who is most important? Please give details.

8. Are there any drawing features which you think are not helpful for you to find who is most important? Please give details.

9. Are there any drawing features which you think help you to find how many groups in a network? Please give details.

10. Are there any drawing features which you think are not helpful for you to find how many groups? Please give details.

11. Any other comments and recommendations about how to draw social networks to make you easily read graphs and understand the social network?

B 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 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?

C Screen shots of the online system

D Sociograms Examples
Figure 15: Screen shots of the online system.
Figure 16: Sociograms for the advice network used in the study.