HCI Evaluation Methodology Applied to Graph Layout Ambiguity

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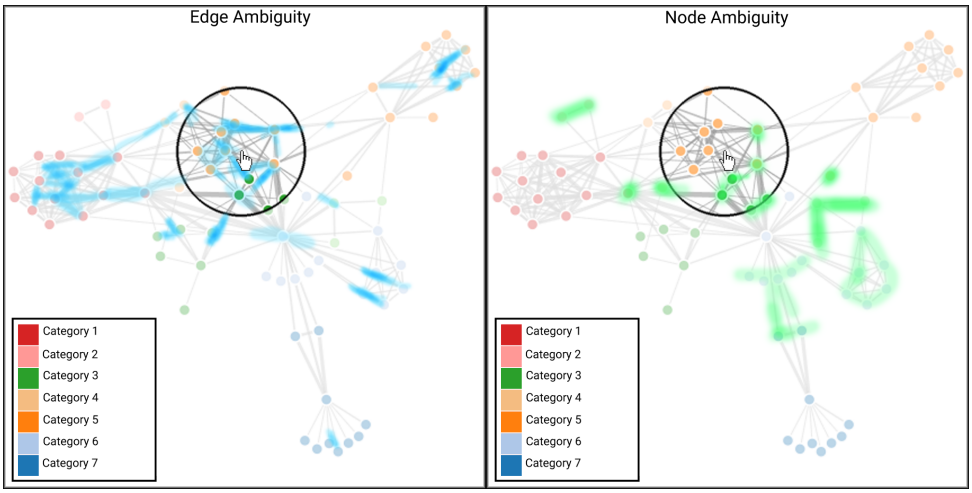


Abstract

This paper describes a proposed improvement upon the AmbiguityVis model of visualizing spatial ambiguity in graph layouts [1]. A significant problem with the original model was that the researchers did not perform any human-centered design interviews and only evaluated their solution with with expert users. To address this, we performed human-centered evaluation with ten novice users to determine the effectiveness of AmbiguityVis. We found that many of our users were confused by the visualization and had a hard time understanding it. As a result of these interviews, we then propose a model similar to AmbiguityVis and instantiate recommendations from our users and best human-computer interaction practices in a high-fidelity interface prototype.

1 Introduction

1.1 Background

The issue of how best to lay out graphs to clearly and efficiently display the relevant data has been the topic of research spanning decades of work. In fact, finding the optimal way to lay out a graph is an NP-hard problem [2]. As will be shown in the Related Works section below, many have tried to address this problem with varying levels of success. Generally, methods used to lay out graphs tend to focus on certain facets of the graph's aesthetics, though this can lead to trade-offs with effective communication of the graph's data.

Towards the end of effective and efficient graphs, Wang et al. [1] produced a method they call AmbiguityVis to visualize ambiguities in a graph - points where a user might become uncertain as to what the graph is trying to convey. Building off prior literature, the researchers begin by defining an "ambiguity" as a problem that falls into one of the following three classes:

Figure 1: An example of AmbiguityVis's approach to better graph layout visualization. From left to right: The original graph, in which node color represents a certain category of data; the convex hull of the graph; and two heatmaps showing visualizations of different kinds of node-based ambiguities.

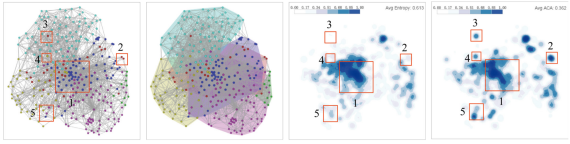
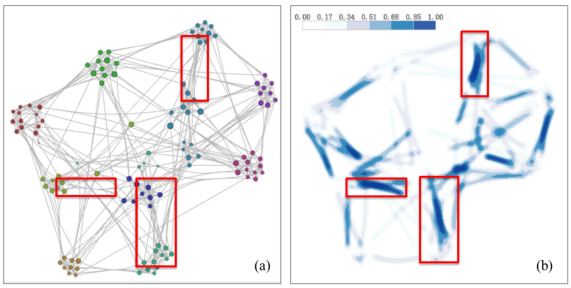


Figure 2: Another example of AmbiguityVis's approach output, this time focusing on edge-based ambiguities.



- Ambiguities in the spatial relationships between nodes and edges
- Visual overlap between community structures
- Visual ambiguities resulting from node/edge aggregation (such as edge bundling)

They propose metrics to measure these three classes of ambiguity and use the metrics to build a heatmap of the most "ambiguous" points on a given graph. Ideally, the researchers claim, this system can be used to identify potentially confusing areas of graphs, helping users to choose the most effective layout algorithm for their data by showing the areas that need the most aesthetic assistance. Figures 1 and 2 show two examples of graphs and their respective AmbiguityVis-generated heatmaps. After evaluating AmbiguityVis throug two expert review two case studies, Wang et al. found that AmbiguityVis visualizations helped analysts quickly and easy localize potential visual problem areas on graphs, which then helped them decide how the issues could best be addressed. As such, the AmbiguityVis team presented a novel way of looking at visual ambiguity in graphs and showed that it could be effective in certain situations.

1.2 Motivation

One relatively important issue with AmbiguityVis's visualizations is that they can be strikingly unclear to novice users and those who don't have anyone to explain the tool to them. The heatmap may not intuitively make sense to less-experienced users, since heatmaps are generally used to visualize spatial clustering of information, not the intensity of problem areas. Thus, a new user might not understand exactly what the AmbiguityVis heatmaps are representing.

In addition, though AmbiguityVis has been shown to be useful to experts in the field, the researchers themselves stated that they wanted to improve upon their product using human-centered design practices. Therefore, we will follow their proposed future work and evaluate AmbiguityVis through a user-centered lens. This will allow us to see if AmbiguityVis is indeed as effective at visualizing problems as it claims to be.

We believe that this is a worthy research direction to explore because of the potential to produce a better version of AmbiguityVis. A tool such as this would be useful not only in visualization research and acadamia, but possibly industry as well - perhaps in realms such as big data work, neural network mapping, or biological and chemical sciences. This wide array of applications leads to a wide array of potential end users. If we can identify what parts of AmbiguityVis can confuse those users, we will be able to improve upon it to create more useful visualizations of graph layout ambiguity.

1.3 Hypothesis

We propose that if a novice user were to view the AmbiguityVis heatmap without any clear signifier describing its purpose, the user would not be able to tell what the heatmap was attempting to convey - thus suggesting the ineffectiveness of AmbiguityVis. This is because heatmaps tend to be used to visualize spatial or temporal clustering of data points, not necessarily intensity of problems.

Further, we propose that if we conduct human-centered evaluations of AmbiguityVis, we will be able to leverage users' recommendations and insights to improve upon the visualization and create a more effective way of visualizing ambiguity in graphs.

1.4 Research Questions

To explore the above hypothesis, we will focus our investigation on the following research questions:

1. Is AmbiguityVis effective at conveying its intended purpose to novice users?
   (a) What, if anything, do novice users find confusing or misleading about AmbiguityVis?
2. What features would novice users find useful in interacting with the AmbiguityVis model?
3. What improvements to AmbiguityVis are suggested by novice users, human-computer interaction literature, and known best practices?

1.5 Approach

To approach the above research questions, we will begin by conducting human-centered evaluations with potential users of AmbiguityVis. We will collect their responses to a set of semi-structured questions and analyze their responses to determine what about the AmbiguityVis visualization can be improved. We will also draw on best known HCI practices in usability engineering to suggest improvements.

We will use these suggestions to improve upon AmbiguityVis's prior work by creating a high-fidelity paper prototype that showcases our improvements and increases the effectiveness of the visualization.

2 Related Works

There are many facets to Ambiguity Viz, each of which focus on specific areas. The three specialties that were chosen to be explored more thoroughly are: Graph Drawing and Visualization, Graph Drawing Readability Metrics, Measuring the Visual Separability of Communities. Each of these methods used algorithms to calculate overall simplicity and comprehension for graphs.

The Measurement of the Visual Separability of Communities focuses on how easy it is to differentiate the different clusters of nodes present on any given graph. As node clusters are an important feature of a graph since they provide more information on the data shown, it is impervious that the clusters are not overlapping each other and muddling the graph. Another paper by M. Sips, et. al [5], discussed the importance of the distinguishably of node clusters and formulated an algorithm that is capable of identifying the ease of understanding of the clusters.

Graph Drawing Readability Metrics' main goal is to create a metric that represents the similarity between the graph and the overall structure. Much of the research in this section is done through human-centered testing where people judge a graph based on it's clarity, and by how easy it is to gather data. C.Dunne, et. al [3] analyzed the difference in how humans can perceive several types of graphs, and which can be read and understood more efficiently.

Graph Drawing and Aggregation is one of the more covered topics and has been analyzed for decades. It's main purpose is to create the algorithms that provide clear graph layouts that contain networks that are capable of scaling gracefully and without creating large clusters of edges. This is important as most graphs are not able to maintain their clarity when they scale due to crowed edges, therefore the biggest problem was coming up with an algorithm that can create such a graph.

3 Methodology

AmbiguityViz is a human centered visualization method used to reduce the ambiguity of node-edge graphs. There are several ways to solve the problem of improving a visualization. This paper takes an HCI approach to decrease ambiguity through an iterative 'query -> revision' structure. Relevant users are queried for feedback on the design, which is used to revise attributes of the ambiguity visualization. As a result the clarity of the graph increases, and another improvement cycle can be made.

3.1 Users

Users of the ambiguity viz system could come from many disciplines, but primarily come from STEM professions. This project will focus on biology related majors. Ambiguity viz identifies areas of confusion in a graph, allowing them to be minimized and the graph structure improved. Due to the fact that there is no objective "best" way to layout a graph, this study is limited to users that handle and interact with categorical, relationship-heavy data that would gain clarity from being presented in a graph layout. Potential users of the ambiguityviz system will be interviewed for their demographic information - age, major, grade level, and graph theory experience. The interviewee will then be asked a series of carefully selected questions to gather information about the current state of the system.

3.2 Interview

- Research Question 1
  - Show the user a graph and its ambiguity heat map side by side
    - Ask: Do you think these two models are related?
    - Ask: If so, how are they related?
  - Ask: If you were trying to understand the data represented by this graph, what parts (if any) might confuse you?
    - Make note of "lightbulb" moment when/if the user realizes that the heat map represents the ambiguity of the graph.
    - Notify user of the relationship if they did not reach that conclusion.
  - Ask: Do you think representing the ambiguity of this graph with a heat map gave you insight into the data that you may not have gained from the graph by itself?
- Research Question 2
  - Ask: If this data were a visualization for <xyz> data in your field, what kinds of features would you expect to have to allow a better understanding of the data.
- Research Question 3
  - Ask: What other ideas do you have for improvements to this model?
  - Ask: What are your final thoughts or points of confusion/clarity on this model?

4 Results and Discussion

In total, we ended up interviewing ten novice users to determine the effectiveness of the AmbiguityVis visualization. These users were recruited as a convenience sample from a population of undergraduate students on the Oregon State University campus. As discussed above, we limited our recruitment to students in the biology field or closely related majors. The users ranged in age from 21 to 27 years old. Some of the majors were Biology/Pre-Med, Computer Science with an applied option in Bioinformatics, and Bioengineering. None had more than a rudimentary understanding of graph theory or graph layout. A more complete list of user demographics can be found in Appendix A.

Overall, we saw varied reactions to the AmbiguityVis visualization among our participants. Some were more adept at determining the relationship between the graph and the heatmap than

others, which is to be expected in such a sample. However, users generally tended to express confusion towards the AmbiguityVis model - either not understanding its intended purpose or not seeing why such a visualization would be useful.

4.1 RQ1: Is AmbiguityVis effective at conveying its intended purpose to novice users?

The answer to our first research question seems to be a resounding "No". Our users were generally unsure of what the heatmaps were trying to convey and often did not even recognize that the heatmaps and graphs were related. Participant 10 summed these feelings up well:

> "I feel really stupid now... it's so obvious now that you've pointed it [the relationship] out, but I just couldn't see it at all until then ... there was no way to tell what the heatmap was trying to show."

Other users identified some sort of relationship between the graph and the heatmap, but were mistaken in what the relationship was. For instance, the researcher that interviewed participant 4 wrote that "He did have a sense of density from the color changes in figure 1 and 2, however he had no idea what it meant or if it particularly mattered." Similarly, participant 7 had a notion that the hottest parts of the heatmap represented some kind of probability, such as the probability that there was a node of the graph located in that location on the canvas. Though it is easy to see how our participants could have gotten confused (since the hottest parts of the heatmap tended to correspond to places with many nodes or overlapping edges), this interpretation is not quite correct.

Finally, some of our users were influenced by their biological science background. Participant 8 didn't see the heatmaps as heatmaps at all, instead guessing:

> "One looks like a virus and one looks like a bacteria."

Clearly, the original AmbiguityVis visualization is not obvious or intuitive to novice users. Thus, this makes the case that we can improve upon it to create a better visualization.

4.1.1 RQ1a: What, if anything, do novice users find confusing or misleading about AmbiguityVis?

Very few of our users thought that the heatmaps of ambiguity added any extra information to the graph that they would not have been able to see "just by looking at it". In fact, some users found it more confusing than helpful. Though the reasoning that they could just "look" at the graph and see what the heatmaps conveyed may be an example of hindsight bias after researchers pointed out the relationship, users definitely were unsure that the heatmap had any value at all.

Some of the participants were mislead by the heatmap's chosen colors. For instance, participant 10 thought that the green hues of the node ambiguity heatmap corresponded somehow to the green-colored nodeson the graph itself. Once he made this assumption, his understanding of the heatmap devolved - he began to look for relationships between the green nodes and the heatmap, rather than ignoring the colors of the graph's nodes. Though the choice for the coloring of nodes on the graph was arbitrary, this is a good example of users' tendencies to assign meaning to colors where none is meant to exist. As such, this informs our improvements by suggesting we be judicious in our coloring choices.

Either way - whether users inferred no relationship between the graph and heatmaps or they inferred the wrong relationship - this points to a lack of information that leads to incorrect assumptions. These assumptions influence the ways that users view the data and can have unintended results. Without any signifiers or any information provided about how to interpret the AmbiguityVis visualization, it is very confusing to novice users.

4.2 RQ2: What features would novice users find useful in interacting with the AmbiguityVis model?

One feature that the majority of our users requested was the ability to have the heatmap overlaid on top of the graph, rather then simply placed next to it. This would allow an easier comparison between the hot areas on the heatmap and the graph itself - users would not have to perform the

context switch moving from the heatmap to the graph, instead seeing them as both part of the same data set. This would likely help users recognize that the tow parts were indeed related and might lead to a clearer understanding of the model and provide another dimension to the data.

Another request users echoed in different forms was the ability to interact with the data somehow. Currently, AmbiguityVis is a static visualization, consisting only of a heatmap and a graph, printed on a piece of paper. If we were to implement AmbiguityVis on a website, we could add interactive elements to the graph and heatmap that gave users the ability to delve deeper into the data or zoom out for a broad view if they wished. Some examples of these features could be zooming in on certain points on the graph, hovering over a node to get more information about it, or "turning" the graph by clicking and dragging it if it were 3D.

4.3 RQ3: What improvements to AmbiguityVis are suggested by novice users, human-computer interaction literature, and known best practices?

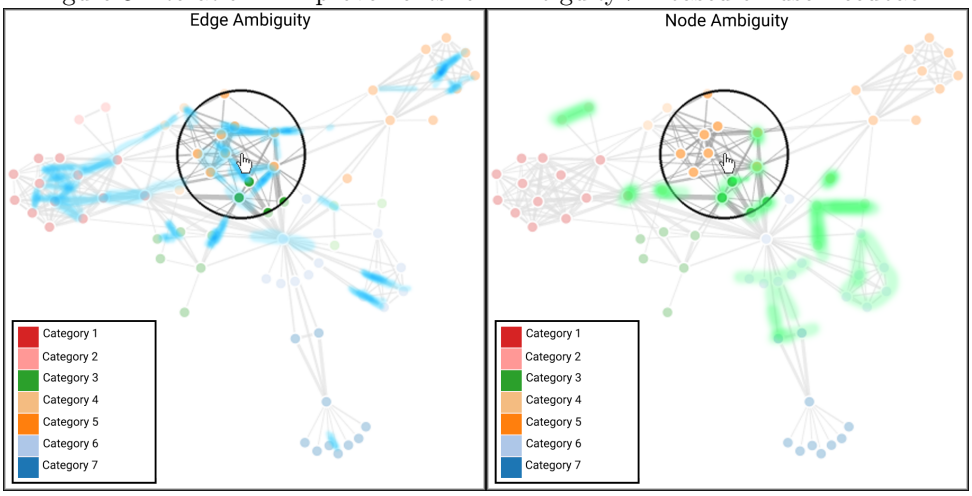
From our research and results, we came up with three main classifications of improvements:

- From information visualization and human-computer interaction literature: Adding user interaction to the model would likely help users understand the model better and provide an element of user control over the data.
- From out users: We should overlay the heatmap on top of the graph rather than setting the two parts side by side. This will explicitly suggest some sort of relationship to the user, since people tend to assume that two items that are spatially co-located are related in some way, as per Gestalt Laws of perception.
- From our users: We should add some sort of label or legend to the model so that the data being conveyed is clear even when there is no one to explain the model to the user. Otherwise, there is no way to tell what the model is trying to show.

5 Implementation

Based on the feedback compiled from ten user case studies, we have formed a visualization for iteration 2 of the system. This updated implementation includes labels such as a legend and a visualization title. Additionally, the ambiguity visualization was overlaid over the original graph to provide context for the heat maps. In order to keep focus on the ambiguity visualization itself, an interactive element is added in the form of a 'circle of clarity' that reveals the underlying graph when the user hovers over the visualization.

Figure 3: Iteration 1 improvements for AmbiguityViz based on user feedback



6 Limitations & Future Work

In the future, we would plan to implement an A/B testing approach by building multiple implementations of the system for user review. This would allow users to provide a direction for their improvements, based on which of the provided implementations they prefer.

Arguably the most important aspect of designing this system is the user review. Chosen users need to be relevant and provide detailed feedback. Once users are chosen, it is important to get feedback from those users over multiple iterations of the system to allow users to provide context based feedback. It is unreasonable to expect these users to conduct multiple interviews over time without some sort of compensation, due to the lengthy and in depth nature of the interviews. A possible solution to this problem is the creation of an interface that allows users to easily review the current iteration of the system remotely and at their own convenience.

While the user data we obtained was crucial for the implementation of a better visualization, if given more time we would have liked to have groups from several different majors rather than just a group of Biology related majors. This could have provided us with even more pivotal data, for instance a Marketing major with experience dealing with social network type graphs could have a vastly different opinion than that of a STEM major.

7 Conclusion

The AmbiguityViz system is a novel method for visualizing the ambiguity of a graph, allowing the graph visualization to be modified to better visualize the data it represents. This paper presents an HCI centered method for improving the usability of AmbiguityViz.

The method involves query/revision cycles that begin by interviewing a series of people who would be potential users of the improved AmbiguityViz. Their feedback and interaction is recorded and analyzed. The results are compiled together and used to improve the system, increasing usability. The approach was chosen due to the fact that different users have unique values when it comes to a graph's layout. This fact prompted the exploration of a Human Centered Interface methodology to improving AmbiguityViz.

As with the original AmbiguityViz system, this approach is limited. Users may know what is confusing about the current iteration, but that feedback is not guaranteed to lead to an improvement of the system. There are many concepts to learn by taking an HCI approach to system development, especially when the development is focused on the way users interact with the system.

This paper revolves around the implementation of a single query/revision cycle of improving AmbiguityViz. In order for this approach to be effective however, many cycles must be made. The primary constraint this project faced was time. With more time, progress could have been made on implementing an interface past the mock-up and design phase.

8 References

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9 Appendix A: Interview Data

9.1 Demographics

- Subject 1
  - **Age** - 27
  - **Major** - Computer Science Applied Bioinformatics
  - **Experience** - Used graphs throughout degree, uses python to visualize them somewhat often
- Subject 2
  - **Age** - 21
  - **Major** - Bioresourch Research with Chemistry and Toxicology minors
  - **Experience** - Uses software in lab that uses graphs, knows the basic concepts from schooling
- Subject 3
  - **Age** - 23
  - **Major** - Bio and Health Sciences
  - **Experience** - Has experience with node linked structures through working with genetics class work.
- Subject 4
  - **Age** - 28
  - **Major** - Bio Engineering
  - **Experience** - No explicit experience with node linked structures or graphs. Implicit knowledge from general understanding.
- Subject 5
  - **Age** - 22
  - **Major** - Bio Engineering
  - **Experience** - Basic experience with node link graphs.
- Subject 6
  - **Age** - 25
  - **Major** - Chemical Engineering
  - **Experience** - Little to no experience with node link diagrams.
- Subject 7
  - **Age** - 21
  - **Major** - Animal Science/Pre-Veterinary
  - **Experience** - No experience with node-link graphs
- Subject 8
  - **Age** - 21
  - **Major** - Biology
  - **Experience** - No experience with graphs
- Subject 9
  - **Age** - 21
  - **Major** - Biology/Pre-Med

- **Experience** - No experience with graph theory

- Subject 10
  - **Age** - 22
  - **Major** - Biology/Political Science double major
  - **Experience** - No experience with graph theory

9.2 Research Question 1

- Subject 1
  - **Relationship** - Graph had a clustering or categorical layout due to the colors. Figure 1 seems to share some edges with the graph and the same general shape, perhaps it represents the most traveled edges? Figure 2 seems unrelated.
  - **Confusion** - There is no key for the data category, unsure what different colors represent. The edges don't have any sort of distance metric; what determined the distance between nodes and groups of nodes? The large clusters are messy and unorganized, it would be hard to observe any individual nodes in the clusters.
  - **Insight** - Figure 1 provides context for the graph, it represents the ambiguity of the graph well. Figure 2 was vague until I was told specifically what it meant (the colors represent different categories and the fig.2 heat map is the confusion in assigning those nodes to a cluster).

- Subject 2
  - **Relationship** - Figure 1 and Figure 2 look kind of like heat maps, hard to tell what they are for exactly. They are related, Graph and Figure 1 seem to share some structure.
  - **Confusion** - There are no labels on this interface at all. "I would fire the person that made this". Perhaps Figure 1 represents areas with the most connectedness?
  - **Insight** - The heat map of ambiguity could be useful, but if the graph is confusing enough to need a map of ambiguity, perhaps a graph is not the best way to visualize the data.

- Subject 3
  - **Relationship** - Believed that there was a corrilation between the graphs and and their respective figure 1. She felt that there was a concentration of data based on the dark aspects of the heatmaps.
  - **Confusion** - She thought that both figure 1 and 2 were bacteria colonies and that the graph represented some insight into why they developed their colonies a particular way.
  - **Insight** - Though the heatmaps were correctly attributed to density, they were incorrectly interpreted. The heatmaps alone were to the intepretation of the user.

- Subject 4
  - **Relationship** - Held the understanding that there was no corrilation between either of the graphs and their respective figures.
  - **Confusion** - Since the user had no inherent insight coming into the question, there was a a large amount of confusion on what he was particularly looking at. He did have a sense of density from the color changes in figure 1 and 2, however he had no idea what it meant or if it particularly mattered.
  - **Insight** - Without the basic understand of graph theory it's possible that there would be no way of truly understanding a standalone graph. A signafier would have enabled the user to understand what they were looking for.

- Subject 5
  - **Relationship** - Figure 1 seemed to be related to the graph, but could not discern how. Figure 2 did not seem related at all.

  - **Confusion** - There is no keys or labels that show what this heat map is representing.
  - **Insight** - Did not understand what they were looking at until I explained. Still had trouble grasping the concept even after explanation.

- Subject 6
  - **Relationship** - They thought that they were somewhat related as general shapes looked familiar, but didn't know how the heat maps related to the graph exactly.
  - **Confusion** - No labels or any general signifier that explained the relationships.
  - **Insight** - After explanation, subject 6 was able to understand the relationships, but still did not see a use for this visualization.

- Subject 7
  - **Relationship** - Yes - thought that the bottom figures were the representations of the probability that there was a node on the graph in that location. Darker color -> more likely for there to be a node there. Not sure what the edge graph meant, though.
  - **Confusion** - Knew there was a relationship there, but couldn't tell exactly what without labels or some other kind of signifier.
  - **Insight** - Said "oh that makes sense" when I pointed out the relationship. Saw they were related, but really had no idea how. Didn't seem to find the heat maps super useful or adding anything to viewing the data.

- Subject 8
  - **Relationship** - Made a face when question was asked. "One looks like a virus and one looks like a bacteria". Said they weren't related because she didn't see anything that matched up.
  - **Confusion** - Don't see any reference points - doesn't know what anything represents. "I don't know what any of this means"
  - **Insight** - Didn't happen until I pointed out the relationship. Still seemed kind of skeptical.

- Subject 9
  - **Relationship** - Thought they were related - saw the same general shape. Thought the heatmaps were showing subsets of the data, but which subsets - she wasn't sure.
  - **Confusion** - Tons of lines overlap each other, and it's hard to tell what connects to what.
  - **Insight** - Did understand they were related.

- Subject 10
  - **Relationship** - Assumed there was a relationship there just because they were on the same page, but for the life of him couldn't see what it might be. Thought maybe the dark green dots in the node heatmap were partial data.
  - **Confusion** - Didn't have labels. "how could I get any information about this??"
  - **Insight** - Didn't happen until I told him about it. Even then was a bit skeptical and needed convincing. Can see it in the graph but really didn't think it added anything you couldn't see from just looking at the graph.

9.3 Research Question 2

- Subject 1
  - **Context** - Expected a legend, information about edge length and what distance between nodes meant to put the ambiguity in context. Interactivity with the graph, zoom and pan, move points around. More information about the context of the graph.

- Subject 2
  - **Context** - If this graph represented the classifications for various substances in a toxicology context: Labels would be required. Interaction would also be expected, such as sorting and filtering to simplify the data, and panning or zooming. Perhaps the lines could be highlighted when you click on them to eliminate ambiguity.
- Subject 3
  - **Context** - Could see how finding problems within the graph would be helpful, however couldn't give a specific reason as to why. They did really want a legend or signafiers as to why there were certain colors being represented on the graph.
- Subject 4
  - **Context** - Since the user had no context as to what it the graphs could be used for, he was prompted with the idea of a social network. He believed that having a 3D graph would be useful in viewing the hidden connections, allowing you to move the perspective on which lines were visible or on top of one another.
- Subject 5
  - **Context** - The user did not have much experience with node link diagrams, and as a result did not know what this visualization could be useful for.
- Subject 6
  - **Context** - The user was not able to think of a use for this visualization nor thought that this visualization clarified things.
- Subject 7
  - **Context** - Wants tables, to see the data as numbers. Likes the raw data. Wants to be able to overlay the heatmap on the graph to better show the correspondence. Also though that it would be nice to hover over the dots and have it highlight all the ones that were connected to it / related to it in some way - more granular control over data view.
- Subject 8
  - **Context** - Figure 2 (nodes) was more helpful than figure 1 (edges). Didn't think either really added more information than you couldn't have gotten just by looking at the graph though.
- Subject 9
  - **Context** - Gives an idea of how much you could rely on that graph and glean information from it. If you can't say with certainty the graph is like "this" then it makes it harder to analyze the data
- Subject 10
  - **Context** - Did NOT think the heatmap added anything. Found it more confusing than helpful.

9.4 Research Question 3

- Subject 1
  - **Improvements** - The heat maps would serve their purpose better if they were overlaid on the graph, and the focus was taken away from the graph.

  - **Final thoughts** - The ambiguity graph for nodes (figure 2) makes the whole thing more ambiguous - not accomplishing its goal. Demonstrated a clear understanding of graph theory and had experience using visualizations of them in the past. Subject thought the idea was useful, but the execution was poor. System needs to provide context between the graph and the ambiguity visualization. The graph itself needs to have clear context in order to understand what ambiguity in this data means.

- Subject 2
  - **Improvements** - In this iteration, ambiguity figures should be laid over the graph data. The context just isn't there without these two things being overlaid.
  - **Final thoughts** - Generally this is confusing. Not sure that ambiguity viz is necessary - a human can determine what is confusing much more quickly than a program. Plus, if your data is confusing when represented in a graph layout, a graph probably shouldn't be used to visualize the data. This user was very familiar with representing data in a biological context, they work in a toxicology lab and deal with scientific data very often. They don't think that ambiguity should be a factor in the visualization of the data - if there is ambiguity then the data should be displayed in a different manner, or split up into multiple visualizations. The system could be useful, but not in its current state.

- Subject 3
  - **Improvements** - The participant really wanted to see how the graphs would look with context and with the heat maps placed on top of them.
  - **Final thoughts** - She kept feeling like the heat-maps were bacteria.

- Subject 4
  - **Improvements** - The user really wanted to see how the graph would look in three dimensions.
  - **Final thoughts** - He had no other pertinent comments.

- Subject 5
  - **Improvements** - Adding labels and change the color of the heat map to red.
  - **Final thoughts** - Not sure what this visualization is trying to do as people are clearly able to see confusing spots on graphs.

- Subject 6
  - **Improvements** - Adding context and labels to show what the heatmap was representing.
  - **Final thoughts** - Overall, they were not able to see an obvious use for this visualization and the representation of ambiguity was quite ambiguous itself.

- Subject 7
  - **Improvements** - Add tables so that the original data can be seen too. Add ability to overlay graphs on top of the heatmaps so the correspondences are more obvious. Hovering over a node should bring up more information about the node.
  - **Final thoughts** -

- Subject 8
  - **Improvements** - Add the ability to zoom in on "hot" parts of the heatmap - would let you try to figure out exactly what was confusing. Magnifier option too. "Looks like it should be 3D" - wanted the ability to turn the graph (click and drag interface type thing). When you click on a node, it should pop up information about it.
  - **Final thoughts** -

- Subject 9

  - **Improvements** - Overlay the heatmap on the graph - hard to connect without it. Lines are faint and hard to see on the graph itself - could be better colors. More info would also be nice - a key, or some other way of getting context.
  - **Final thoughts** -

- Subject 10
  - **Improvements** - Overlay heatmap - with a color that's not already on the graph (because got confused with blue map/blue nodes). Labels. Figure 1 (edges) can help you look for relationships but figure 2 is a bit more confusing.
  - **Final thoughts** - "I feel really stupid now... it's so obvious now that you've pointed it [the relationship] out, but I just couldn't see it at all until then ... there was no way to tell what the heatmap was trying to show"