# How do People Make Sense of Unfamiliar Visualizations?: A Grounded Model of Novice's Information Visualization Sensemaking

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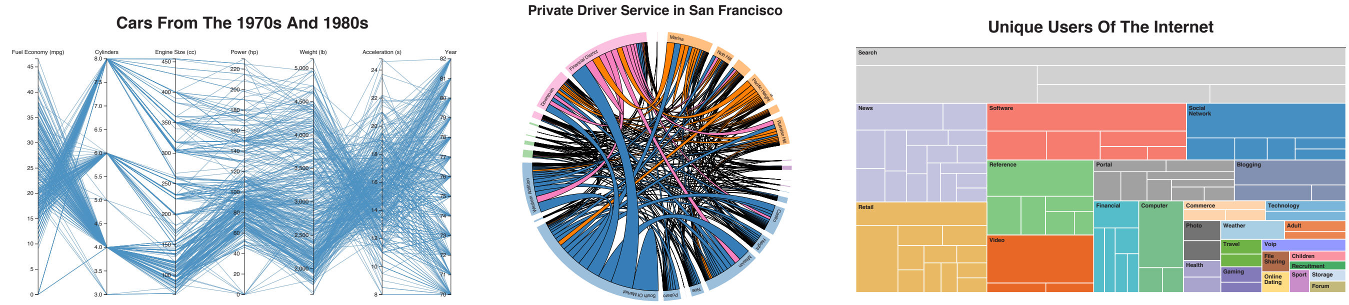


(a) Parallel-coordinates plot (b) Chord diagram (c) Treemap

Fig. 1. The three unfamiliar information visualizations that were used in this study: (a) the parallel-coordinates plot (PCP), (b) the chord diagram (CD), and (c) the treemap (TM).

**Abstract**— In this paper, we would like to investigate how people make sense of unfamiliar information visualizations. In order to achieve the research goal, we conducted a qualitative study by observing 13 participants when they endeavored to make sense of three unfamiliar visualizations (i.e., a parallel-coordinates plot, a chord diagram, and a treemap) that they encountered for the first time. We collected data including audio/video record of think-aloud sessions and semi-structured interview; and analyzed the data using the grounded theory method. The primary result of this study is a grounded model of NOvice's information VIsualization Sensemaking (NOVIS model), which consists of the five major cognitive activities: **1** *encountering visualization*, **2** *constructing a frame*, **3** *exploring visualization*, **4** *questioning the frame*, and **5** *floundering on visualization*. We introduce the NOVIS model by explaining the five activities with representative quotes from our participants. We also explore the dynamics in the model. Lastly, we compare with other existing models and share further research directions that arose from our observations.

**Index Terms**—Sensemaking model; information visualization; novice users; grounded theory; qualitative study

## 1 Introduction

Recently, it has become more common to see various types of visualizations for the general public. Well-known newspaper companies, for example, *The New York Times*, are actively using visualizations in order to deliver news and opinions with data. Furthermore, new types of visualizations are getting the spotlight as online data storytelling is gaining interest and popularity as we can see through the Tapestry conference. In the past, most of the visualizations that were shown to the general public were primitive visualizations (e.g., line charts, bar charts, and pie charts), however, this is no longer the case.

Even though various visualizations are exposed to the general public, it does not matter what visualizations are used and what the underlying stories are if the visualizations do not make sense to the users and audience. As visualization researchers, we should design communicable visualizations and promote the usage of visualizations for the general public. However, we have less understanding on how people make sense of information visualizations. Although some visualization researchers have recently begun to explore the assessment way of visualization literacy, a user's ability to use and interpret a visualization, through a couple of workshops [1] and a paper [6], we have very few studies that carefully describe how a user makes sense of a visualization that they encounter for the first time with comprehensive and empirical evidence as Liu and Stasko [29] have pointed out.

Thus, the goal of this study is to investigate **how people make sense of unfamiliar visualizations**. In particular, we are interested in "novice users" that can be defined as users who have seen a particular type of visualization for the first time. For example, if one sees a parallel-coordinates plot for the first time, the person is a novice user for the parallel-coordinate plot. By focusing on observing novice users when they endeavor to make sense of unfamiliar visualizations, we try to understand the information visualization sensemaking activities. Sensemaking can be defined variously depending on the discipline [21, 22, 35, 36]. However, we refer to *information visualization sensemaking* as "conscious efforts to achieve understanding of how to interpret visual objects and underlying content in an information visualization" in this study.

The main contributions of this study are as follows:

- We propose *a grounded model of NOvice's information VIsual-*

[1] IEEE VIS 2014 Workshop: Towards An Open Visualization Literacy Testing Platform and EuroVis 2014 Workshop: Towards Visualization Literacy

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*ization Sensemaking* (NOVIS model) to describe how a novice user makes sense of an unfamiliar information visualization.
- We share further research directions that arose from our observations.

## 2 Background

### 2.1 How Novice Users Making Sense of Visualizations

Compared with copious literature regarding what kinds of tasks and activities conducted on visualization, there are only few of studies conducted on the topic of how a novice user makes sense of a visualization. We found two studies investigating how novice users interact with visualizations. Grammel et al. [18] observed novice users' behaviors while constructing visualization with a given data set and found obstructions ("barriers" in their term) in the process. Likewise, Kwon et al. [26] explored challenges ("roadblocks" in their term) faced by novice users in investigative analysis while using a mature visualization tool, Jigsaw. However, the novice users in their studies more likely mean "users those who are not familiar with information visualization and data analysis" and "non-expert users in investigative analysis," which differ from the "novice users" in this study, who have seen a particular type of visualization for the first time.

The most relevant work we found was a recent work by Peebles et al. [33], which investigated how people, who are not familiar with a parallel-coordinates plot, make sense of this visualization. They, eventually, identified the following factors hindering proper interpretation: (1) prior knowledge of coordinate systems and (2) crossing lines and visual clutter. While their findings are insightful, they did not provide a comprehensive description of the sensemaking activities or processes of their participants.

### 2.2 Graph Comprehension

More comprehensive work has been done in the field of *graph comprehension*. Most of these studies were conducted with relatively primitive visualizations without interaction techniques, such as line charts, bar charts, or pie charts. According to Friel et al. [17], many researchers considered graph comprehension as reading and interpreting graph.

One interesting finding was that many researchers (e.g., [4, 9, 15]) in graph comprehension converged into three levels of graph comprehension: the elementary level (can read a specific value in a graph), the intermediate level (can read relationships or trends in a graph), and the advanced level (can read beyond what is presented in a graph). However, we quickly found that not only the three levels of graph comprehension are rather simplistic to explain more comprehensive cognitive tasks with advanced visualizations, but also the studies did not clearly explain how a novice user achieves the elementary level with an unfamiliar visualization.

More interestingly, we elicited the following four factors influencing graph comprehension: (1) graph formats, (2) visual characteristics, (3) knowledge about graphs, and (4) knowledge about content [16, 43]. We would like to provide a summary of the factors below.

**Graph Formats** Different graphs have different effects on graph comprehension [16, 42]. The graph formats are highly related to characteristics of tasks or purposes [24, 43] with the support of empirical studies [45, 48]. For example, line graphs are better for retrieving trends and interactions; bar charts are better for identifying individual data points; and pie charts facilitate proportion judgements [45].

**Visual Characteristics** Other visualization characteristics (e.g., color, shade, animation, and data density) affect graph comprehension [43]. This factor arose from graphical perception, which is the decoding process of information encoded in visual variables [4, 12, 17]. In addition, the graphical perceptual tasks were empirically verified in terms of accuracy [12, 30].

**Knowledge About Graphs** Obviously, prior knowledge about graphs influences the level of graph comprehension [15, 16]. If a graph reader possesses prior knowledge about a particular graph, the graph reader would easily translate visually represented information in the graph into conceptual knowledge [42]. When a graph format supports expectations that are formed by the knowledge about the particular graph, it positively influences graph comprehension, however, if the expectations are inconsistent with the graph format, it is likely that the graph reader makes errors in interpretations of the graph [43, 33]. Some researchers described the knowledge of graphs as a *graph schema* [34, 43].

**Knowledge About Content** Lastly, knowledge about content affects graph comprehension [15, 16, 43]. A graph reader can identify the content of a graph from a title, labels, and other textual information in the graph and retrieve associated familiar knowledge about the content [15]. The retrieved familiar knowledge can be previous experience or domain knowledge. The knowledge about content influences graph comprehension in three ways: trying to confirm the knowledge, keeping track of information in the graph, and finding errors [42]. Similar to knowledge about graphs, prior knowledge about content forms expectations or beliefs about data [16]. In particular, Kosslyn [25] pointed out that a graph reader's previous knowledge about graphs and content is one of the major factors to interpreting graphs.

In a generic perspective, Shah and her colleagues proposed a model of graph comprehension based the four factors. According to the model, the first two factors influence bottom-up processes; the last two factors influence top-down processes; and, eventually, graph comprehension involves the interaction between bottom-up and top-down processes [16, 41, 42]. However, the major assumption of the model is that a graph reader has knowledge about the graph format [41].

### 2.3 Other Models of Sensemaking

In spite of copious work in the field of graph comprehension, we were not able to find a clear answer to our research question, how novice users make sense of unfamiliar visualizations. Thus, we expanded our literature review into sensemaking in the field of human-computer interaction and information visualization to collect relevant information.

A well-known sensemaking model is a notional model of analysts sensemaking loop by Pirolli and Card [35]. The model describes the intelligence analysts' cognitive processes from searching external data to presenting to audience. However, this model obviously does not focus on novice users and, furthermore, does not explain how the users make sense of unfamiliar visualizations.

Another model is the data/frame theory of sensemaking by Klein et al. [22, 23]. We found that this model might be quite relevant to our study because the model focuses on the seven sensemaking activities and describes how people construct and revise internal mental structures (they call it "frame") when they make sense of external events. They defined data as "the interpreted signals of events" and frame as "the explanatory structures that account for data" [23] (p. 120). Depending on data from the events, people refine the existing frame (i.e., elaborating cycle) or put effort to construct a new and better frame (i.e., re-framing cycle) based on the seven sensemaking activities.

The notion of the internal mental structure was further refined and applied to the field of information visualization by Liu and Stasko [29]. They paid attention to the dynamic relationships between mental structure (they call it "mental model") and external visualization, and described visual reasoning and interaction in this perspective. Although they emphasized the interactive nature between the internal mental structure and visualization, it was not detailed enough how the internal mental structure is created from a visualization and how an individual make sense of a new visualization using the internal mental structure, which are referred to as *internalization* and *processing* in their paper.

## 3 Methods

In order to fill the identified research gap, we conducted a qualitative study by observing how novice users make sense of unfamiliar visualizations. The experiment mainly consisted of three observation sessions and a semi-structured interview. During an observation session, the experimenters observed how a participant makes sense of one of three visualizations while the participant thought aloud [2, 11]. The semi-structure interview was conducted to find any complementary findings that might be missed in the observation sessions.

### 3.1 Visualizations

In order to conduct the experiment within a reasonable time frame, we selected three instances of information visualization for this study (i.e., the parallel-coordinate plot (PCP), the chord diagram (CD), and the treemap (TM) as shown in Figure 1) based on the following criteria. First, we wanted to expand the diversity of visualizations. Thus, we considered a diverse set of underlying data structures: multivariate data, network data, and hierarchical data [20, 32]. Second, we wanted to select visualizations with which most of our potential participants are likely not familiar with. Thus, we ruled out visualizations that K-12 curricula covers (e.g., line charts, bar charts, histograms, scatter plots, and pie charts) [17]. Finally, we chose the specific visualizations and data sets from visualization libraries [2,3] and a news article [4], and modified the visualizations according to our needs.

The contexts of the data sets (i.e., car, driver service, and the Internet) did not require specific expertise. The data that we used in the PCP was a car data set, which describes car models released from 1970's to 1980's. It contained main specifications of the cars (e.g., fuel economy, cylinders, engine size, horse power, and weight). For the CD, we used a data set that describes the frequency of rides through a private driver service, Uber, between various neighborhoods in San Francisco. However, in our pilot study, we noticed that some participants did not know the company "Uber," therefore we modified the title using general terms in the actual experiment. For the TM, we used a data set collected by the Nielsen Company, which describes the number of unique users of the top 100 websites within January, 2010.

Each visualization had a title, describing what they were about. In addition, each visualization had a minimal set of interaction techniques that were essential to use it properly [47]. In the PCP (Figure 1(a)), a user could select a line of interest by moving a mouse cursor on the line (Select) and filter data points by brushing along any axes (Filter). In the CD (Figure 1(b)), a user could filter data points by moving a mouse cursor on an arc (Filter) and find more details on a specific data point from a tool tip (Elaborate). In the TM (Figure 1(c)), a user only had the same tool tip feature as in the CD (Elaborate).

The three visualizations did not have any instructions that directly explained how to interpret the visualizations because, during the pilot study, we noticed that think-aloud sessions were quite uneventful if a detailed instruction was given. It became more like observing a reading comprehension task, rather than a visualization sensemaking task. Furthermore, we believe that if a user learned how to interpret the visualization from an instruction, the user is no longer a novice user. Thus, we decided to hide detailed instructions on how to interpret visualizations. We realize that this setting is somewhat artificial, but we believe that this setting provides a chance to see how our novice users attempt to make sense of the unfamiliar visualizations.

### 3.2 Participants

A total of 13 participants [5] (9 females, ages ranging from 20 to 60 years old ($\mu = 32.23$, $\sigma = 12.89$)) were recruited from a university in the United States. All the participants had basic computer skills, such as using a standard keyboard and a mouse. Particularly, we recruited only native English speakers since the verbalization using a non-native language can be an obstacle during thinking aloud [11, 37]. In order to recruit participants with a diverse demographic background, the experiment was announced through a central announcement channel of the university (6 participants were undergraduate students and 7 were university staff members). All the participants were volunteers and they were compensated with $10 for one hour of participation.

### 3.3 Apparatuses

A desktop computer with Microsoft Windows 8 along with a 19-inch LCD monitor (1280 × 1024 resolution), a standard keyboard (however, the participants did not need to use a keyboard during the experiment), a mouse, and a USB desktop microphone were used. In order to record the verbalization of the participants and the experimenter as well as the participants' interactions with the visualizations through the mouse, a screen recording software, Camtasia Studio 6, was used.

### 3.4 Procedure

The experiment was conducted in the following steps. After obtaining the signature on the authorized consent form from a participant, we provided the overall instruction about the experiment. Then, we introduced the think-aloud method with some demonstration of how to do it. The participant took two practice sessions to familiarize themselves with the think-aloud method. In the demo and practice sessions, we intentionally did not use any information visualizations in order to minimize exposure to any visualizations. After the demonstration and practice sessions, we conducted three observation sessions. For each session, a randomly selected visualization out of the three visualizations (Figure 1) were used. The experimenter began each session with the following question: "Please verbalize your thoughts and behavior while trying to make sense of the visualization." There was flexibility in how long the participant spent on each session and the session ceased when the participant expressed the end of his/her sensemaking (e.g., *"I think that is it"* or *"Okay, that is pretty much I got"*). We provided a break between the sessions to the participant in order to minimize the effect of fatigue from each session. After all three sessions were finished, we conducted a brief semi-structured interview with the participant to clarify what the experimenter observed. Both the observation sessions and the interview were recorded. Lastly, the participant was asked to fill out a demographic survey questionnaire. The entire procedure for a participant took approximately one hour.

### 3.5 Analysis

#### 3.5.1 Data Prescreening

One challenge in recruiting our participants was that we needed to confirm that the participants had not seen the three visualizations before. However, we were not able to show the visualizations to the participants before the sessions to check the eligibility because it would contaminate them. Thus, we asked "Have you ever seen this type of visualization before?" in the post semi-structured interview in order to know if the participants had prior knowledge of the three visualizations. Although we intentionally chose the not-commonly used visualizations (see Section 3.1), in 13 out of 39 sessions, the participants reported that they had seen the similar visualizations previously. However, further investigation (e.g., "Oh really, where did you see? Could you describe the visualization?") revealed that they were confused with irrelevant visualizations (e.g., confusing the PCP with a line chart). As a result, we removed the following five sessions from our data analysis: P02-PCP, P11-PCP, P04-TM, P09-TM, and P11-TM because these participants showed that they were not novice users for the corresponding visualizations. We analyzed the remaining 34 sessions.

#### 3.5.2 Analysis Procedure

All the recordings from the observation sessions and semi-structured interviews were transcribed. Then, we analyzed the transcription from the observation sessions using the qualitative inquiry approach [14, 39] and used the semi-structured interview results for the data triangulation purposes. Particularly, in order to come up with an understanding that was grounded in data from the participants, we followed a structured manner and procedure, grounded theory [10, 13]. As Creswell emphasized, grounded theory "generates a general explanation (a theory) of a process and an action shaped by the views of participants" [14] (p. 83). By following the grounded theory method, researchers can develop a general explanation does not come from existing models or theories but generated in data from the participants [14]. The general process of grounded theory consists of three coding stages: open coding, axial coding, and selective coding (theoretical coding or conceptual coding). The open coding stage involves segmenting data by proper size of excerpts, identifying concepts, and

[2]http://bl.ocks.org/jasondavies/1341281
[3]http://bost.ocks.org/mike/uberdata/
[4]http://news.bbc.co.uk/2/hi/technology/8562801.stm
[5]Originally, we recruited 14 participants, but the data from P01 were dropped as the participant's data were corrupted due to technical issues.

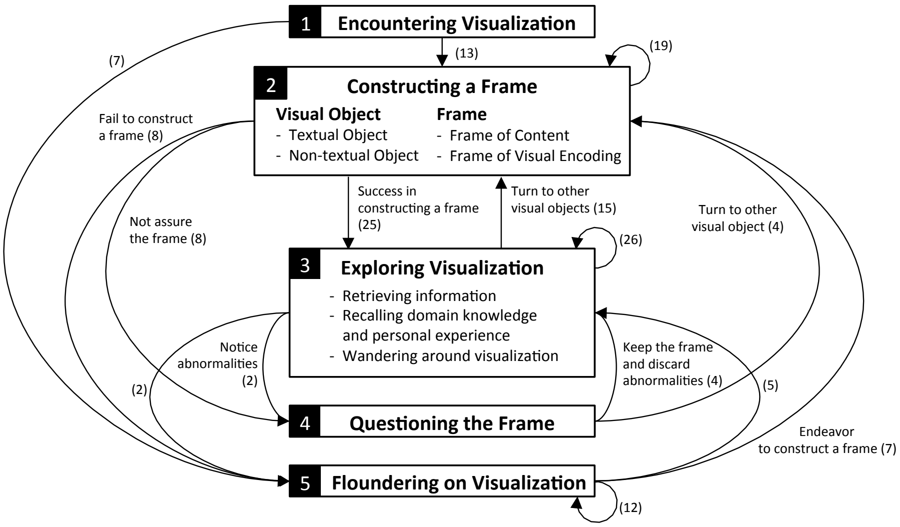



Fig. 2. A Grounded Model of Novice's Information Visualization Sensemaking (NOVIS model). The arrows indicate the major transitions between the five activities and the numbers in the parentheses indicate the number of transitions between the activities what we observed from the data.

categorizing excerpts; the axial coding stage involves identifying high-level phenomena and central ideas; and the selective coding stage involves taking and conceptualizing the central phenomenon and developing a narrative [7].

Three of authors began open coding from the perspective of interpretivists [10, 13, 27]. To precisely characterize the participants' processes of making sense of the visualizations and reflect on the contents and nuances of the data, we also used audio/video recordings while coding. In particular, we followed Allen's key point coding method [1] to determine the efficient excerpts' sizes. After the coding process, we drew an affinity diagram in order to categorize the codes and to see similarities and differences. In the axial coding process, we reassembled the open codes and the categories of open coding, and then identified a core phenomenon while our participants made sense of the three visualizations through several iterations of this process [14, 39]. During the iterations, the coder generated several (six) versions of potential models and had intensive discussion sessions with all of authors. Eventually, we were in agreement on the last version of the potential models. In the final selective coding process, we crystallized the core phenomenon of novice users' information visualization sensemaking and reviewed relevant quotes from the coded data.

## 4 Findings

By employing the grounded theory method, we attempted to identify cognitive activities of information visualization sensemaking that our participants demonstrated. As a result, we identified the five most salient cognitive activities and observed that the participants traversed the five activities. Based on the result, we developed **a grounded model of NOvice's information VIsualization Sensemaking (NOVIS model)** (Figure 2).

### 4.1 Two Core Concepts

Before explaining the NOVIS model in detail, we would like to clarify the two terms in here:

**Visual Object** A *visual object* is "any identifiable, separate, or distinct part" (p. 227) as defined by Ware [46]. Visual object is akin to "data", which is defined as "the interpreted signals of events" (p. 120), in the data/frame theory of sensemaking by Klein et al. [23]. However, we use visual object instead of "data" because we believe the term "data" could be confusing in the context of information visualization. Visual objects can be broadly categorized into two: **textual objects** and **non-textual objects**. Textual objects are objects that are represented in alphanumeric text format (e.g., a title, legends, axis labels, and data labels in a visualization). Non-textual objects are any objects that are represented in non-textual format (e.g., polylines and axes of the PCP, chords and arcs of the CD, and boxes of the TM). Some non-textual objects have one or more visual encoding schemes (e.g., in the TM, number of unique users for a website is encoded in size of box and category of website is encoded in color of box). Thus, an information visualization can be considered as a composite set of textual and non-textual visual objects. We marked textual and non-textual objects using the TM in Figure 3.

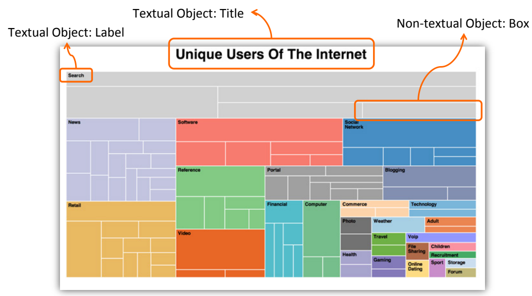



Fig. 3. Examples of textual objects and non-textual objects with the TM.

**Frame** A *frame* is defined as "an explanatory internal structure that accounts for visual objects" according to Klein's definition [23]. Based on our study, we noticed two distinctive types of frames: **frame of content** and **frame of visual encoding**. A frame of content is an explanatory internal structure that explains underlying topic and data. For example, if one thinks, "Hmm, this visualization is about different websites" while interacting with the TM, the thought is a frame of content. Likewise, a frame of visual encoding is an explanatory internal structure that explains how to interpret non-textual objects. If one thinks, "Ah, I think that the size of each box means a number of users for each website," the thought is a frame of visual encoding.

### 4.2 Five Activities in the NOVIS Model

As shown in Figure 2, the NOVIS model consists of the following five activities as well as miscellaneous activities:

- 1 Encountering visualization
- 2 Constructing a frame
- 3 Exploring visualization
- 4 Questioning the frame
- 5 Floundering on visualization
- M Miscellaneous

In this subsection, we would like to introduce the activities in the NOVIS model with representative quotes from our participants.

#### 1 Encountering Visualization

We defined *encountering visualization* as the cognitive activity in which a user faces and looks at an information visualization as a whole image. Obviously, this activity usually happens at the very beginning of each session. However, in 13 out of 34 sessions, the participants did not clearly verbalize their encountering as shown in Figure 4(a).

In this activity, the participants did not actively try to make sense of the visualizations yet. However, we thought that this activity was distinctive comparing to other activities because the participants appeared to build their first impression during this activity. In the think-aloud sessions, we observed that the participants expressed feelings or opinions about impressions (e.g., *"a really crazy chart"* (P02-CD)), overall layout (e.g., *"a lot of rectangles and sort of squares"* (P06-TM)), colors (e.g., *"a bunch of colors, bright colors"* (P12-TM)), and complexity (e.g., *"oh, my goodness, that's impossible to follow because there are so many blue lines, and they overlap so much"* (P07-PCP)) of the visualizations.

### 2 Constructing a Frame

We defined *constructing a frame* as the cognitive activity in which a user attempts to construct a frame to make sense of a given visualization. In our study, the participants often constructed their initial frames after the encountering activity ( 1 ), but we often observed that the participants revisited this activity after other activities.

It should be noted that there were different types of frames that our participants attempted to construct. As we discussed in Section 4.1, there are two major types of frames, which are frame of content and frame of visual encoding. When the participants attempted to construct a frame of content, they often relied on textual objects (e.g., the title, axis labels, or data labels) as shown in the following quote [6]:

> *"Let's see. Financial district, downtown, western addition, south of market, [...] Okay. Private driver service in San Francisco [...] It sounded like neighborhoods. So private driver service in San Francisco. [...] if that means private driver picking you up where you are and taking you somewhere in a car."* (P13-CD)

When they attempted to construct frame of visual encoding, we noticed that the participants attempted to build a potential frame of visual encoding by conjecturing what each visual encoding scheme meant. Interestingly, they also tried to confirm whether the potential frame was appropriate by comparing the interpretation of a visual object and a corresponding textual object or prior knowledge. For example, P09 successfully constructed a frame of visual encoding (i.e., meaning of each polyline) in the PCP by the aid of the title and labels (i.e., textual objects) and the prior knowledge (i.e., knowledge about cars):

> *"Cars from the 1970s and 1980s [...] fuel economies, cylinders, engine size, cubic centimeters, power and horsepower, weight in pounds, acceleration seconds, [...] There's blue lines connecting from each graph to the other [...] I think each line represents like a singular automobile."* (P09-PCP)

Obviously, the participants sometimes constructed incorrect frames and such incorrect frames negatively influenced further sensemaking activities. Interestingly, regardless of whether the constructed frames were correct or not, the participants relied on the frames to explore the visualization ( 3 ). We also observed that some participants failed to construct a frame, which will be further discussed in Section 4.4.1.

### 3 Exploring Visualization

We defined *exploring visualization* as the cognitive activity in which a user interacts with an information visualization to discover facts and insights from the visualization based on the constructed frames ( 2 ). The behaviors could be categorized into three sub activities: retrieving information, recalling domain knowledge and personal experience, and wandering around visualization. We listed the three sub activities under the exploring visualization activity because the three sub-activities often happened together and it was challenging to separate them cleanly as the examples in this section show.

[6] Embellishments on some visualizations [3, 5] actually may be helpful to construct frame of content, but such cases have not been observed in this study because the three visualizations did not have such embellishments.

**Retrieving Information** We observed that the participants retrieved various information while exploring the visualization. First, the participants retrieved specific data values by reading textual objects (e.g., words and numbers) in the visualization. Particularly, since the participants already had a frame of content in their mind, they were able to interpret the values within the frame (e.g., *"It says Burling Heights, 0.9 percent of origins so he really doesn't start there very often because it's only less than 1 percent, but if I go up here that's 4 percent so he starts off at Russian Hill a lot more."* (P03-CD)).

Likewise, the participants were able to retrieve information by interpreting non-textual objects because they had frames of visual encoding to account for the non-textual objects. When they retrieved information using non-textual objects, they showed the behaviors of comparing, ranking, grouping, and finding patterns in the visualization rather than reading specific data values. For example, P06, who constructed a frame of visual encoding (i.e., meaning of size of box), ranked the social network services in terms of the number of users by comparing the size of the boxes in the TM:

> *"I see that Facebook has the most it looks like because it's the biggest box in the Social Network's square or rectangle. Then it looks like the second biggest is Twitter and then Orca, LinkedIn, Classmates, and Meebo look like they're pretty similar in the number of users."* (P06-TM)

In addition, another participant, P09, discerned interesting patterns by interpreting lines between pairs of axes in the PCP as correlationships:

> *"One is under 20 always seem like they go up to eight cylinders, and ones over 20 are migrating down to four. And then the one is with four cylinders have engine sizes that correlate with the fewer cylinders, and the horsepower is lower of course."* (P09-PCP)

**Recalling Domain Knowledge and Personal Experience** During the exploring visualization, we observed that some participants recalled domain knowledge and/or personal experience. This is exactly what Liu and Heer describe as "Recall" [28]. These activities were often used to check whether they knew a specific textual object in the visualization or not, and they frequently mentioned *"I know what it is"* or *"I've never heard of that."* Interestingly, P09 tried to explain why the specific pattern between the year and fuel economy or acceleration emerged in the PCP using his/her specific domain knowledge (i.e., oil crises in 1973 and 1979):

> *"It actually seems most fast cars were produced in 1970. [...] that's also because with the oil crisis people are focusing more on the fuel economy over here rather than how fast it goes."* (P09-PCP)

A number of participants recalled their personal experience while exploring the visualization. For example, P04 recalled an experience of visiting a friend who lived in San Francisco while exploring the CD:

> *"San Francisco - I have a friend who lives in San Francisco. We took the train, pretty much, into town."* (P04-CD)

Recalling personal experience did not seem to contribute much to a deeper exploration of the visualization. However, it is worth noticing that people showed recalling in not only domain knowledge but also personal experience, which was not directly related to the content of the visualization.

**Wandering Around Visualization** As a sub activity of exploring visualization, we also observed some participants read text on a given visualization without any specific order. In this case, they successfully built frames of content and visual encoding already in the previous activity ( 2 ) thus, they knew what the visualization was about and how to interpret the visual objects. They often did the retrieving information activity based on the constructed frames. However,at some point, they just skimmed through textual objects, especially labels, until they found another interesting point or moved on to read a different visual object. This behavior would seem to be similar to retrieving information on the surface but the participants just read textual objects one by one meaninglessly. For example, the following quote represents this behavior with the TM:

*"Shopping dot com, ShopZilla, Target, Best Buy, Priceline, Free. [...] Sears, software, Microsoft. [...]."* (P08-TM)

### 4 Questioning the Frame

We defined *questioning the frame* as the cognitive activity in which a user begins to doubt the constructed frame or tries to verify the frame. This activity occurs when a user is uncertain about the frame after constructing a frame ( 2 ) when he/she finds abnormal visual objects that are not compatible with the frame while exploring visualization ( 3 ). Through this activity, the user tries to confirm that the constructed frame is reasonable to explain the visual object and he/she can adopt the frame to explore the visualization.

In the think-aloud sessions, we found that a number of participants showed clear evidence for the activity of questioning the frame. For example, P12 constructed a frame of visual encoding by conjecturing the meaning of colors of arcs in the CD:

*"That's orange, and I'm wondering if there's a reason why that's orange [...] Thinking that maybe the colors could have to do with geographical location in San Francisco."* (P12-CD)

However, P12 was not confident about the frame because of his/her lack of knowledge about San Francisco. Then, P12 tested and, finally, confirmed the frame with another part of the arcs in the CD:

*"I don't know really anything about San Francisco, so I don't know where any of these places are located, [...] Noticing here though, there's a green section [...]. When I hover over this [...], inner Richmond, outer Richmond, outer Sunset, and then, Golden Gate Park, so I'm going to guess these are still parts of San Francisco."* (P12-CD)

### 5 Floundering on Visualization

We defined *floundering on visualization* as the cognitive activity in which a user does not know what to do with an information visualization because the user failed to construct any reasonable frames. Since a user does not have proper frames to account for visual objects, visual objects in the visualization do not make sense. Thus, it often leads him/her to be frustrated and confused.

For example, we observed P04 who fell into the floundering activity with the PCP. It seemed that P04 failed to construct not only a frame of content after reading the title and/or labels but also a frame of visual encoding to account for lines in the PCP. P04 expressed confusion and superficially described visual objects in the visualization as follows:

*"Cars from the 1970s and '80s and a topic I don't like. [...] It's kind of hard to tell what I'm actually following. [...] So there's like, okay. This one I can highlight and a blue thing came over here, but that's just highlighting those areas. So that's not helpful. [...] What is that? Oh, my goodness."* (P04-PCP)

Based on our observations, we found that the following quotes commonly represented the floundering on visualization activity: *"I don't know," "what does this mean?"* and *"I'm not really sure what this is."*

While external user behaviors in this activity might seem to be similar to those in wandering around visualization of the exploring activity ( 3 ), they are inherently different behaviors. Contrary to the floundering on visualization activity, a user has a constructed frame which he/she can base the exploration upon in the wandering around state.

From our observation, we also found that there were mainly two ways to deal with the activity of floundering on visualization. The first was to give up making sense of the visualization. In this case, the participants exhibited confusion and superficially described objects that caught his/her eyes, and then finished the think-aloud session. In contrast, some participants made an effort to seek and construct a frame so that they would make sense of the visualization (see Section 4.4.2).

### M Miscellaneous

On top of the five activities, the participants demonstrated other activities and we categorized the activities as *miscellaneous*. As well as minor quibbles that arose while interacting with the visualization (e.g., *"The line's kind of thin, so they're kind of hard to hover over."* (P09-PCP) and *"It's sort of hard to read the ones that are upside down."* (P13-CD)), it includes interesting comments from the participants. They provided positive and negative comments, and even suggestions of a new representation.

For example, P07 appreciated the representation of the TM by comparing it to a visualization of what he/she knew, a pie chart:

*"So I guess this works better if you have a lot of things that you would be trying to fit. [...] I guess if you're trying to compare everything within each category to everything else, then it would be hard to have a pie graph because there's so many categories."* (P07-TM)

Interestingly, P04 suggested a new representation instead of the CD:

*"It would be better if you had each location on the top and on the bottom and figured out a way to lengthen that way [...] It shows you in each direction so I guess you could have one line say origination point and then the other destination and then the crossover points and have them all listed and the percentages. [...] It would be much more appealing."* (P04-CD)

### 4.3 Dynamics in the NOVIS model

After identifying the five activities, we explored series of activities of the participants and transitions between the activities. Figure 4(a) represents series of activities that was demonstrated by each participant while making sense of the visualizations. From the results, it is difficult to say that every participant followed a common sequences of activities. Some participants showed a relatively longer series of diverse activities (e.g., P03-TM and P04-CD) while other participants showed shorter activities (e.g., P10-PCP and P11-CD).

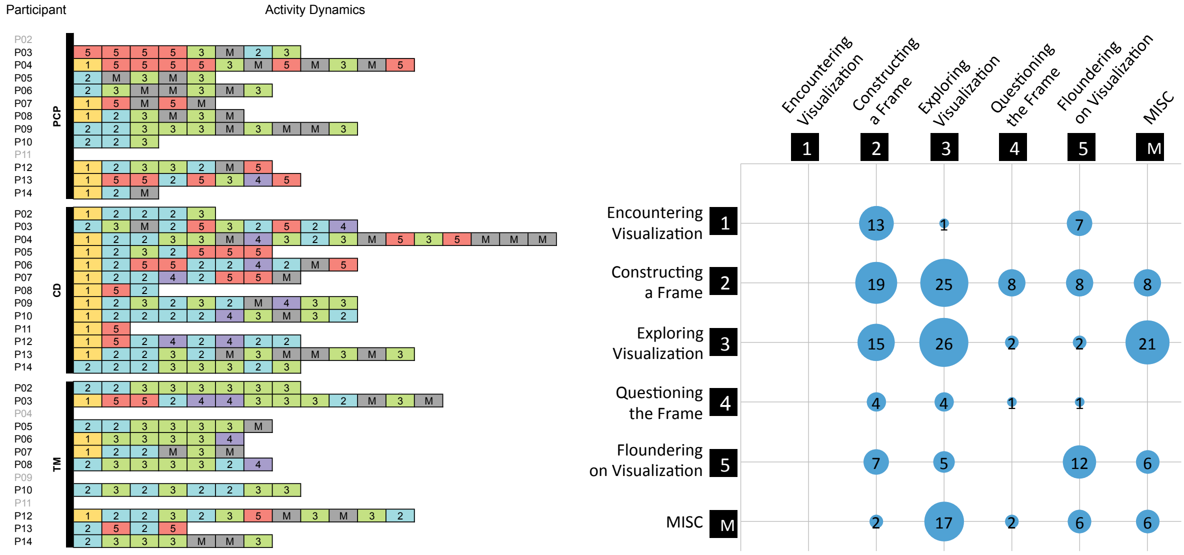
However, different visualizations or underlying data appear to influence the sensemaking activities. The participants floundered ( 5 ) more often with the PCP (17 times) and the CD (15 times) than with the TM (3 times). Furthermore, the most of the questioning the frame activity ( 4 ) were observed in the sessions with the CD (8 times) compared to those with the PCP (1 time) and TM (4 times). These patterns indicate that the participants with the PCP and the CD failed more times to construct proper frames to explore the visualizations than those with the TM. Due to the nature of the qualitative study and a lack of proper control, it is impossible to discern whether different visualizations, data sets, or something else influence these differences. However, we observed that the same participant showed drastically different sensemaking processes depending on the visualizations (e.g., P06 and P13), so it is worthwhile to know that future studies should be conducted to test effects of diverse visualizations and data sets on information visualization sensemaking.

Another pattern in the overall activity transitions of the participants (Figure 4(a)) is that 13 out of 34 sessions do not have the encountering visualization activity ( 1 ). However, we believe that the activity happened and it was merely not verbalized by the participants because we are not able to start a visualization sensemaking without encountering the visualization.

In order to do a deeper exploration of the transitions between the activities in the NOVIS model, we calculated aggregate transitions between the activities as shown in Figure 4(b). From the various transitions between the activities, we found some general patterns in it.

First, from the encountering activity ( 1 ), the participants showed a pattern of transitions to the constructing a frame activity ( 2 ) or the floundering on visualization activity ( 5 ) but rarely to other activities. This pattern would indicate that the participants were required to construct initial frames of content or visual encoding to move to other activities, especially exploring visualization ( 3 ); or the participants floundered on visualization ( 5 ) without attempting to construct a frame because the visualization was too confusing to the participants (e.g., *"Alright. Well, this is really confusing. Orange kind of stuck out to me first. [...] Okay, that's different. Alright, so what does this mean?"* (P11-CD)).

Another notable pattern is that there are many mutual transitions between the constructing a frame activity ( 2 ) and the exploring visualization activity ( 3 ). This pattern would indicate that the participants tried to construct additional frames when they turned to other




(a) (b)

Fig. 4. The dynamics in the NOVIS model: (a) Activities identified in the 34 observation sessions. The numbers (1 to 5) and the letter M in the boxes indicate different activities in the NOVIS model. The grey participant IDs indicate non-novice users; (b) Transitions between activities. The area and number in each circle represent the number of transitions between activities. The rows represent launching activities and the columns represent arrival activities.

visual objects, and then continued to explore the visualization with the constructed frame.

In addition, there are many internal transitions within the constructing a frame ( 2 ), exploring visualization ( 3 ), and floundering on visualization activities ( 5 ). This pattern would indicate the following three sensemaking patterns: (1) the participants tried to construct enough frames so that they could explore the visualization; (2) once the participants started to explore the visualization, they could continue the exploring by relying on constructed frames; and (3) likewise, once the participants fell into the floundering on visualization, they kept doing the floundering until they constructed a proper frame.

Finally, the miscellaneous activities ( M ) were taken back and forth with various activities, but mostly during the exploring visualization activities ( 3 ).

On top of these four patterns, we were able to find some interesting transitions in the sensemaking procedures from our participants. First, we found that there were direct transitions from the exploring visualization activity ( 3 ) to the floundering on visualization activity ( 5 ) and vice versa. Even though it does not seem to make sense, we found from the transcripts data that the participants suddenly changed his/her attention to other visual objects that he/she did not have associated frames and vice versa. For example, P12 was interpreting the TM based on a constructed frame of visual encoding regarding size of box but he/she turned to another visual object (i.e., color of box). Eventually, P12 floundered on the TM and tried to find or construct a frame since he/she did not have a proper frame of color in the TM:

> *"It says Microsoft in the top one. [...] I'm wondering now why some of - how they chose the colors [...] how they color coordinated these."* (P12-TM)

Second, we also found some intriguing results of the questioning the frame activity ( 4 → 2 and 4 → 3 ). If we think about it, it is possible to reject the current frame and construct an alternative frame after questioning the current frame. However, none of the participants demonstrated such cognitive activities. From the transcripts data, we found that the participants kept the current frame and explored the visualization; or just turned to other visual object and tried to construct another frame even though they began to doubt the constructed frame due to uncertainty or abnormalities in the visualization. This pattern indicates that novice users do not tend to revise their frame once it is constructed in their mind and it is worth remembering.

### 4.4 Challenges and Responses

We were also interested in what caused our participants to be in the floundering (challenges) as well as what kinds of effort the participants exerted to overcome the challenges (responses). First, we explored cases when the participants constructed incorrect frames or failed to construct frames. We believed that investigating such cases would help understand how people get to floundering and what causes the floundering. Second, we investigated what kinds of attempts our participants made to escape from the floundering. Understanding the attempts could be helpful to consider design features for helping users escape from floundering with visualization.

#### 4.4.1 Challenges: Incorrect and Failed Frames

As we have mentioned before, we observed that not all of the constructed frames were correct. Particularly, incorrect frames of content and visual encoding cause confusion and frustration in exploring visualization. For example, P13 constructed a wrong frame of visual encoding and tried to explore the PCP based on the frame. However, the retrieved information did not perfectly fit into the frame and, eventually, the participant gave up further engagement in the visualization:

> *"So a car in 1978, maybe it's the average [...] The gold line must be maybe an average for that year. [...] So I don't know. It seems like a complicated graph to me [...] that's about all I know."* (P13-PCP)

In addition, P08 conjectured the meaning of color of arc in the CD was private driver service companies (i.e., *"I guess I should read the heading: Private Driver Service in San Francisco. So, I guess this is all the different companies maybe [...]"* (P08-CD)). This was probably because the participant rushed into constructing the frame by just relying on the title without considering relationship between non-textual objects and corresponding textual objects.

In order to better understand the challenges, we collected the number of right (constructed a correct frame), wrong (constructed an incorrect frame), and failed (failed to construct a frame) attempts for each visual encoding in the visualizations as Figure 5 shows. Even though the PCP looked complicated, it had the relatively simple encoding scheme only for its polylines. We observed five attempts to construct the frame of visual encoding and two attempts were wrong or failed among them. In contrast, the CD had six visual encoding schemes. Generally, the number of attempts to construct the frames associated with chords (18 attempts) was more than the number of attempts to

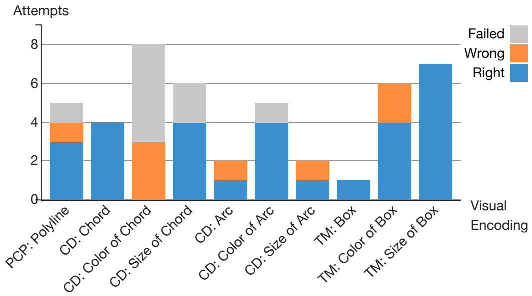



Fig. 5. Observed the number of attempts to construct a frame of visual encoding.

construct the frames associated with arcs (9 attempts). Interestingly, the attempts to construct a frame of visual encoding at color of chord were observed most frequently with the CD (8 attempts), but every attempt was wrong or failed. The similar behaviors were observed with the TM. Although the visual encoding schemes in the TM appeared to be relatively understandable than others, we found that there are wrong attempts only at color of box. It is interesting to see that participants tended to assign some meanings on colors even though these colors did not have any particular meaning as shown in the following quote:

> *"I wonder if the reason why it's that shade of blue is because Facebook uses blue [...] I'm surprised that financial would be blue and not green because I think green and money."* (P12-TM)

### 4.4.2 Responses: Overcoming Floundering

We noticed that some participants, who were in the floundering on visualization activity ( 5 ), endeavored to find and construct a frame in order to account for visual objects that did not make sense. Unlike the participants who gave up making sense of the visualization in the floundering on visualization activity, they gleaned visual objects from the visualization and made efforts to construct a frame. From our observations, we found three strategies that were applied by the participants to overcome the floundering activity.

First, they focused on a certain part of the visualization which they might know or might have been interested in after reading various textual objects in the visualization. The part was usually related to their domain knowledge (e.g., a known website with the TM) or personal experience (e.g., a year of birth with the PCP). While staying with the part, they read the associated textual object carefully and tried to build a frame. For example, P03 mentioned:

> *"Cars from '70s and '80s - I don't know much about cars. I guess when I move the mouse it highlights different lines, [...] it's just fun just to play with the stuff - But I was born in '84 so maybe I should go up here and see '84 [...] A 46, maybe, miles per gallon. It has four cylinders, which I thought maybe the more cylinders you have the faster the car goes [...]."* (P03-PCP)

Second, they focused on gleaning informative textual objects for them from the visualization. By making this effort, they were gradually informed about the content of the visualization and they finally constructed a frame. For example, P12 mentioned:

> *"[...] Let me look here and see what the title says. Private Driver Service in San Francisco. [...] look to see some of the other information that pops up [...] it says 13.7 percent of origins and now I know that it says private driver. [...] it gives me even more information that pops up. It says from south of market to financial district and [...] I'm going to guess that this information is driving routes for private drivers."* (P12-CD)

Last, they tentatively constructed alternative frames that would provide possible explanation of visual objects and compared them. For example, a participant considered the two alternative frames about the size of boxes in the TM and he/she compared them based on the visual objects in order to find a more reasonable one:

> *"So, I don't know if the size of the box has anything to do with how big the company is, or how many users there are. 121 million, 102. No, not necessarily, I don't think. YouTube has 203 million. Apple 119 users. Well, maybe it is by size. Social network, 220 million. [...] The size of the companies - they all companies? Twitter. Twitter's not really a company, or is it?"* (P13-TM)

## 5 Discussion

### 5.1 Exceptional Cases

Although we believe the NOVIS model is a useful framework to understand how novice users make sense of unfamiliar visualizations, it certainly cannot exhaustively explain all the information visualization sensemaking behaviors. We observed some exceptional sessions.

First, there was a participant, P02, who quickly made sense of the TM despite the fact that he/she saw a treemap for the first time. As soon as P02 saw the TM, he/she immediately constructed frames of content and visual encoding:

> *"Okay, this is a graph showing unique users of the Internet and each one of these is - seems like they're organized in amount of [...] they use it."* (P02-TM)

It was not clearly captured by the think-aloud method that how quickly he/she understood the TM. We still do not know how P02 achieved such efficient sensemaking with the TM and the follow-up interview did not provide much clue.

In contrast, there was a participant who intentionally refused to engage in the visualization. For example, P14 refused to engage in the PCP because the content of the visualization was not in his/her interest. However, it was also interesting to see that P14 performed well in the sessions with the CD and the TM:

> *"Cars from the '70s to '80s, so it looks like we're gonna talk about - or it's talking of how fuel economy and perhaps maybe getting better and worse or how many cylinders. [...] Not really a high interest of mine. So I think that that's pretty much all that I see on just the graph."* (P14-PCP)

Emotions aroused by the visualization, personal interest about the content, and how they affect the visualization sensemaking process are not precisely explained in the model. However, it would be interesting to further investigate these exceptional cases (see Section 5.3).

### 5.2 Comparison with Other Models

Since we presented the NOVIS model that is grounded in the data from our participants, it is worthwhile to compare with other existing models in the field of graph comprehension and information visualization.

We believe that the NOVIS model would clearly demonstrate novice users' sensemaking activities that are not described in the existing models. For instance, the cognitive operations of a graph reader are described in the Pinker's graph theory of comprehension [34]. Even though some operations in the model (i.e., having a visual array and creating a visual description) are similar to some sensemaking activities in the NOVIS model (i.e., encountering visualization ( 1 ) and constructing a frame ( 2 )), the Pinker's model does not clearly capture the cognitive activities when a user does not know how to read a visualization because the model assumes that "he or she knows how to read a graph" [34](p. 73). However, the NOVIS model distinctly describe what frustration and confusion a novice user has in the floundering on visualization activity ( 5 ) and we observed the user's attempts to overcome the floundering (see Section 4.4.2).

The graph comprehension model by Carpenter and Shah [8] also has different focus since they did not target novice users as defined in this study. According to the model, interpretive conceptual processes occur after pattern recognition processes in order to transform the pattern to quantitative/qualitative information. This was supported by a series of two experiments that were conducted with college students using line graphs. However, for a novice user, the transition from the perceptual to interpretive conceptual processes would not be smooth with an unfamiliar visualization because they do not have proper explanatory internal structures to conceptualize the perceived visual patterns. We believe that constructing a frame ( 2 ) can bridge the gap between the two comprehension processes for a novice user.

In addition, the NOVIS model would enrich the notionally described existing models with the observed evidence. For example, Liu and Stasko [29] conceptually elaborated the dynamics of internal mental structure in the relationships with information visualizations. However, they did not describe how each level of mental structure is developed. We believe that the NOVIS model could provide a possible description about the dynamics. In particular, the five sensemaking activities in the NOVIS model would describe how the initial mental structure is initially developed and how an individual make sense of a new visualization using the mental structure with the observed data.

On top of that, we indirectly confirmed and validated the interaction of bottom-up and top-down processes in graph comprehension [16, 41, 42]. We observed that the same participant showed different sensemaking processes depending on the visualizations (see Section 4.3) and this observation supports that visualization format would make the visualization easy or difficult to understand. In addition, as seen in the various quotes from the participants, we observed that the participants' prior knowledge about content played a role in the constructing a frame ( 2 ), exploring visualization ( 3 ), and questioning the frame ( 4 ) activities. Furthermore, the participants sometimes relied on prior knowledge about content when they endeavored to overcome the floundering (see Section 4.4.2). From these observations, we would infer the novice user's information visualization sensemaking involves the interaction of bottom-up and top-down processes.

### 5.3 Further Research Directions

Although we came up with the NOVIS model that is grounded on our observations, a number of research questions arose. Due to the nature of qualitative study, we believe that it is worthwhile to share the questions. The following questions should be investigated through further observation and empirical studies in order to deeply understand the novice users' information visualization sensemaking.

First, *what other presentation strategies could be implemented to assist in constructing a correct frame?* One of the surprising behaviors we observed was that participants had difficulties in moving away from initial constructed frames that were incorrect. Out of eight cases when participants had incorrect frames (see Figure 5), there were no participants who realized that they had constructed an incorrect frame and corrected it later on. Thus, the first impression that users get during the encountering visualizations activities is quite important to help users construct a correct frame. Confusing them with too much information might not be a good idea. In this sense, the first step in Shneiderman's mantra, "overview first" [44] should be carefully reconsidered when novice users are expected to encounter a visualization. Although "overview first" has been shown as an effective way to provide a big picture, showing too much information from the beginning might not be a good idea for novice users. Instead, we need to consider other presentation strategies and investigate how the strategies affect the novice users' information visualization sensemaking. Gradually showing visualizations with some instructions, for example, the Martini Glass structure [40], can be a strategy that can be considered for novice users. More directly, selected annotations for a couple of data points could be presented to demonstrate how to interpret them.

Second, *how does personal interest on content affect the visualization sensemaking?* One of the exceptional behavior we observed was that a participant refused to engage in the visualization because its underlying content was not of the participant's interest (see Section 5.1). It might be an important phenomenon in both explanatory and exploratory visualizations. Even though there is a study showing the effect of emotional priming on visual perception performance [19], we need to investigate the influence of personal interest on the novice users' information visualization sensemaking. On top of the personal interest, we need to explore individual factors, for example, mathematical and statistical skills, that could be affecting the sensemaking. Furthermore, we need to study how to promote the users' engagement even if they do not have personal interest about content.

Third, *what are the uncovered sensemaking activities?* For example, we noticed that the exploring visualization activity ( 3 ) could be expanded. In the NOVIS model, we mainly observed the three subactivities within the exploring visualization. If users had more time and motivation and by extension, they were familiar with the visualizations and its content, they could demonstrate other activities, such as formulating a hypothesis, testing the hypothesis, and formulating another hypothesis again, gaining insight and generating interesting questions, iteratively. We believe that these additional sensemaking activities are relatively well captured in other models, such as the notional model of analysts sensemaking loop by Pirolli and Card [35] and the knowledge generation model by Sacha et al. [38]. By combining these two models with the NOVIS model, a more comprehensive model could be developed with additional empirical studies.

Finally, *how do experts make sense of unfamiliar visualizations?* A more fundamental understanding will come from investigating the thought processes of visualization experts. We believe that experts could make sense of unfamiliar visualizations more effectively with different sensemaking processes or activities. If this were to be true, such understanding would help us design effective strategies for educating the general public, so that they can have the ability to properly and accurately interpret visualizations.

### 5.4 Limitations

In this study, we must admit some limitations due to the nature of the think-aloud method. A prime limitation of the think-aloud method is that the participants might miss some of their thought processes during the think-aloud sessions. As Nielsen et al. [31] pointed out, participants' thought processes might be faster and more complex than they can verbalize. Furthermore, thinking aloud is uncommon in a natural setting when they interact with an information visualization. Thus, it might be impossible for us to comprehensively observe the participants' thought processes to make sense of the visualization.

Another concern is that we only used three types of information visualization: the parallel-coordinates plot, the treemap, and the chord diagram. While we attempted to diversify visualization types that we used, it was impossible to comprehensively use all kinds of visualizations. Given the influences of different visualizations we observed in our study, more studies with other visualizations are necessary.

Finally, the experimental setting of having a standalone visualization could be unrealistic. In many cases visualizations are used during a presentation with additional explanations or in an article with textual contents. These narratives would have definitely helped participants to better understand the visualization. However, in order to focus more on the visual representations, we made a trade-off in the experiment.

## 6 Conclusions

In this study, we presented a grounded model of NOvices information VIsualization Sensemaking (NOVIS model), which consists of five sensemaking activities: 1 *encountering visualization*, 2 *constructing a frame*, 3 *exploring visualization*, 4 *questioning the frame*, and 5 *floundering on visualization*. We believe that this is one of earliest qualitative studies that meticulously reports the participants' sensemaking activities and their behaviors when they encounter unfamiliar visualizations for the first time.

This study makes the following contributions to the field of Information Visualization. Our efforts draw attention to understanding of novice users' cognitive activities while making sense of an information visualization. We believe that research about understanding of users' cognitive activities should be actively conducted in order to develop communicable novel information visualization techniques. Furthermore, we also believe that the research will lay ground work to develop visualization literacy test items and to improve novice users' visualization literacy.

Certainly, the presented sensemaking model in this study is not a definitive model describing how a novice user makes sense of an information visualization. The model should be updated and verified by further observation and a series of quantitative, controlled, and comparative studies. However, we hope that the NOVIS model will be a first step to understand users' sensemaking activities with an information visualization.

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