Towards Understanding Familiarity Related Cognitive Biases in Visualization Design and Usage

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Abstract

Experts in domains like biology, climate science, cyber, and energy, frequently use visualizations as the principal medium for making analytical judgments or for communicating the results of their analysis to a broad audience. However, scientists are often skeptical about adopting new visualization methods over familiar ones, although the latter might be perceptually sub-optimal. This is due to the use of the *familiarity heuristic*, where the perceived cognitive ease in processing familiar representations of information leads scientists to undermine the effect of visualization best practices. Recent studies have shown that this often results in a discrepancy between scientists' perceived and actual performance quality. It has also been shown that in some cases, participatory design sessions and qualitative and quantitative user studies are able to mitigate the effects of such bias. In this paper, we discuss the potential causes and effects of familiarity related biases with examples from recent studies and reflect on the associated research questions.

1 Introduction

Visualization techniques and systems are generally evaluated based on their perceptual effectiveness in supporting analytical tasks. Design principles and heuristics help guide the mapping across tasks, data types, and visual representations of the data. However, visualizations designed and used by domain experts, are often in conflict with the established best practices. Examples include use of the well-known rainbow color map, 3D-based encoding for non-spatial multidimensional data, spaghetti plots for showing temporal change in numerical data [1], use of many symbols for encoding categorical data [6], etc. Experts are often resistant to using alternative methods to visualize their data, and in most of these cases, disagree about the negative effects of a design problem [6].

We attribute the factors causing experts' skepticism to the *familiarity heuristic*: experts use familiarity as a heuristic for subjectively preferring known methods over new ones and for being averse towards adopting a change in their existing visualization methods [15], although the familiar methods might be perceptually sub-optimal in performance.

In the cognitive science literature, the familiarity heuristic [2] is associated with the bias of availability [17] that suggests "*the likelihood of events is estimated based on how many examples of such events come to mind*". The more familiar a person is with the events, the easier it is to recall them and accordingly indicate a preference for them when faced with choices. For example, consumer behavior is guided by the familiarity heuristic, where people will tend to buy products of brands they are most familiar with [12].

Similarly, experts in different domains tend to use and adopt visualization methods and techniques that are conventional norms in their respective domains, despite their potential shortcomings. This is due to both a lack of awareness about the benefits of adhering to visualization best practices and a high degree of confidence in using the methods that experts are most familiar with.

In this paper, we bring together knowledge gained from past studies to provide a first analysis of the factors that are associated with familiarity related cognitive biases in domain experts, provide examples of effects of the bias on expert judgment, and discuss about research questions that need to be addressed to help detect and mitigate the effects of the bias.

2 Manifestations of the Familiarity Heuristic

In this section, we borrow concepts from the cognitive science literature, and discuss how biases associated with the familiarity heuristic manifest in experts' design and usage of visualization methods, techniques, and systems. In the human-computer interaction literature, the term "intuitive" is often used interchangeably with "familiar". But, this work follows the recommendation of previous research [14] where it has been argued that "intuitive" can be misleading. Use of the term "familiar" helps us contextualize the use of visualizations across diverse domains, where different established practices may exist and thus the degree of familiarity with different visualizations may vary accordingly.

Perceived ease of use. The Technology Acceptance Model [7] prescribes that acceptance of computer-based techniques is largely dependent on their perceived ease of use, which is defined as "*the degree to which a person believes that using a system would be free of effort*". One of the antecedents of perceived ease of use is self-efficacy, which qualifies how confident a person is in her/his own abilities to achieve a desired outcome. Self-efficacy is affected by the degree of familiarity with the task at hand [8].

In the context of visualization usage, the perceived ease of use factor manifests in two cases: i) where experts are more familiar with conventional, hypothesis-driven analysis methods, and ii) where experts design visualizations using familiar tools that can have bad defaults or have inadequate support for analytical tasks.
As compared to other computer-based tools used for data analysis, like the use of scripting languages or Excel, visualizations are a relatively new way for many experts to interact with or present their data. Especially in domains where the use of static scripts facilitates hypothesis-driven analysis, experts often hesitate to adopt a data-driven approach using dynamic visualizations. This is mainly due to the low self-efficacy in switching contexts between understanding their data and formulating alternative hypotheses on the fly [5].

In many science domains, where experts design their own visualizations, the tools they use sometimes have bad defaults. But due to the high self-efficacy of experts in using those familiar tools and a lack of awareness of how choice of visualization methods can affect tasks in practice, they prefer not to alter the defaults. In a study with climate scientists [6], we showed that such lack of awareness can lead experts to disagree with visualization researchers about the implications of poor design choices, especially those related to perceptual factors like clutter, color, etc. Subjective preference for the familiar yet potentially less useful visualizations is a natural connotation of the perceived ease of use factor.

Loss Aversion. Loss aversion [18] refers to the tendency of people to focus more on avoiding losses than on acquiring gains due to the

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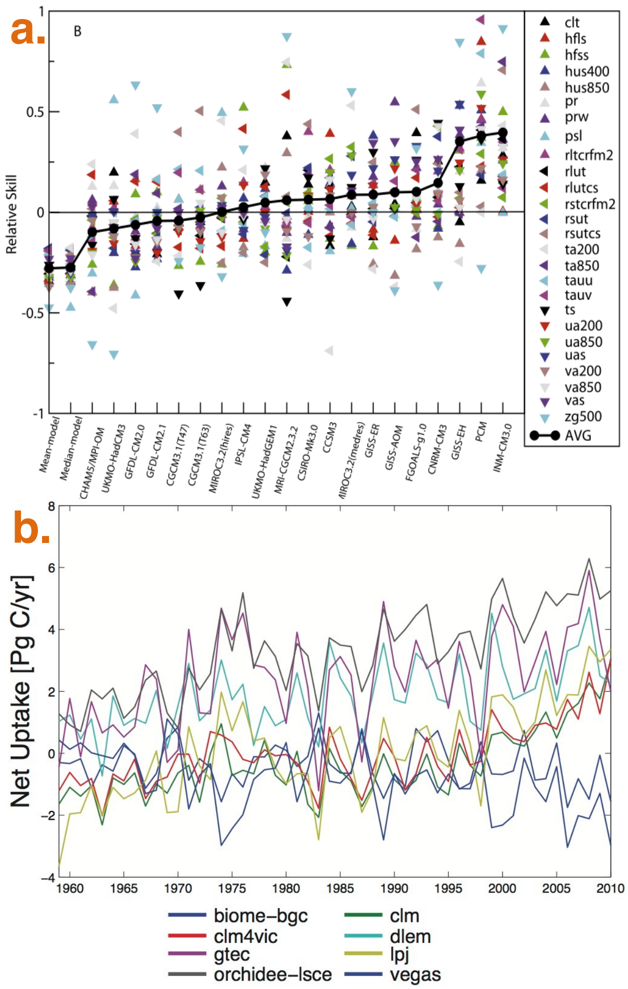

Figure 1: **Examples of familiar visualizations used for climate model comparison.** The use of multiple symbols [9] in a) and that of multiple overlapping lines in the spaghetti plot in b) cause clutter, distract from the main message about similarity of model outputs, and they result from the loss aversion tendency of experts.

perceived psychological impact of losses. This tendency manifests in the context of visualization design when a domain expert plays the role of a data producer or an analyst interchangeably. For example, climate scientists generate modeling data from simulation experiments for describing different phenomena in the earth and the atmosphere, and frequently use visualizations to communicate key messages about the model outcomes to stakeholders within and outside their community. In the course of our interactions with climate scientists [6], we found that even when the message could be conveyed by using abstractions or aggregations, they tended to focus more on avoiding loss of data in their visualizations, than on optimizing the visualizations for gaining insight from them.

This loss aversion tendency resulted in encoding information at a high level of detail, thus causing clutter in the visualization. In Figure 1, we show two examples of this problem with a scatter plot with multiple symbols and a spaghetti plot with many overlapping lines. This tendency can be attributed to the confusion regarding the goal of a visualization: visualizations used for exploration or analysis are not optimal choices for communicating a message. Scientists, who create these visualizations, can easily find patterns in the data due to their high familiarity with it, but others would not be able to spot the same pattern easily unless they are emphasized enough

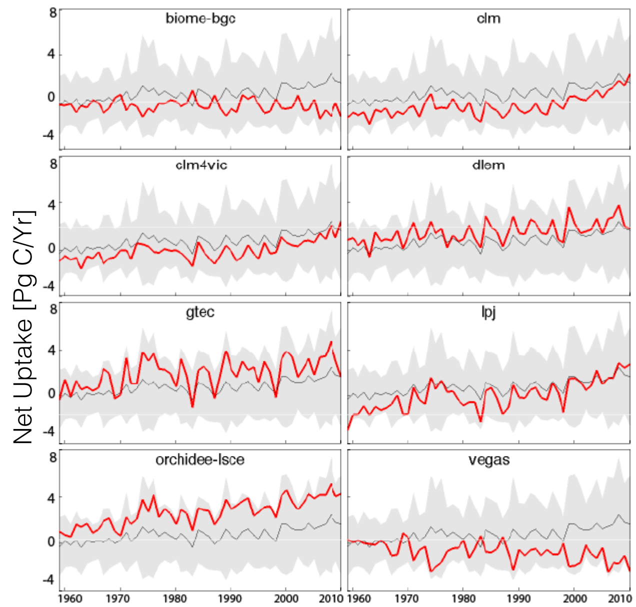

Figure 2: **Modification of the spaghetti plot (Figure 1b) into a small multiples of line charts** could overcome the familiarity barrier and was preferred by a group of climate scientists for visually communicating similarities among multiple model outputs.

in the visualizations. These visualizations can therefore, be suited to scientists' own analysis, but are ill-equipped to communicate a message to a broad audience unfamiliar with the data or the problem domain.

Experts' trust: Similar to interpersonal relationships, in case of human-machine communication, familiarity breeds trust [10]. In a study [16] examining levels of system administrators' trust in familiar command-line interfaces as opposed to unfamiliar graphical user interfaces (GUI), one of the participants remarked: "*Please, no more GUI. If people need a GUI, they aren't qualified to be doing whatever they are trying to do.*" This quote is indicative and representative of the effect of the familiarity heuristic used by most of the participants: an overwhelming majority of them recorded a greater level of trust in command line interfaces although close to half the number of participants indicated greater levels of perceived ease with the GUI. This leads to a follow-on question that if a new analysis medium is able to better solve a problem than the more familiar ones, will experts trust the new medium?

A recent study comparing the use of static scripts with that of a visualization-based system [5] addresses this question. In this study, domain experts, despite their prior familiarity with static scripts, expressed comparable or greater levels of trust in a new visual analytic system. This was true especially in case of complex interpretation tasks where experts had to synthesize insights derived from multiple views of the data to confirm or refute their hypotheses. Similar to the study by Takayama et al., experts also expressed greater levels of perceived ease with the unfamiliar tool. The difference in the study set up here as opposed to that study was the fact that the unfamiliar tool was designed through a participatory design phase with senior researchers. This helped mitigate the potential concerns. due to lack of familiarity, of the bigger group of participants who had never seen the tool before.

3 Effects on Visualization Based Judgments

In this section, we describe how the familiarity heuristic manifests in domain experts' subjective and objective analytical judgments by reflecting on results from recent user studies.

Exploratory study about visualization design problems: In this study [6], we collected about 100 different visualization examples (e.g., maps, scatter plots, and line charts) that are most frequently used in climate modeling for visually expressing similarity among multiple models. We then developed a classification scheme for describing the most common design problems (e.g., clutter, choice of visual variables and color map, etc.) and their consequences (e.g., misinterpretation, inefficiency, lack of expressiveness, etc.). As a next step, we discussed about these problems with a group of climate scientists with a two-fold goal: i) identify cases where experts and visualization researchers agree and disagree about the problem through interviews, and ii) develop solutions to those problems and record their subjective feedback.

We found that in most of the cases, majority of the climate scientists disagreed about the existence and potential consequence of a design problem. Many of these cases involved serious consequences like inaccurate judgment due to inappropriate use of a color map or due to the use of an inappropriate chart that did not adequately convey the intended message. Through our interviews we saw a clear use of the familiarity heuristic, especially in case of the most frequent design problems like the use of a rainbow color map or the use of multiple symbols on a scatter plot. This is reflected in the following comment where use of an alternative color map is perceived as a means to improve the aesthetics and not as a means to solve the task: ”*I agree that the color map can be better but that would be a cosmetic change and wont affect the outcome”*.

We found that the effect of the familiarity heuristic could be mitigated in some cases when we collaboratively designed solutions for a subset of the familiar yet problematic visualizations. The solutions were designed keeping in mind the loss aversion tendency: the encoding could retain the fidelity of the data as much as possible, while at the same time, convey the main message about models that are similar or different. For example, as a solution to the spaghetti plot (Figure 1b.), we designed a visualization with small multiples of line charts (Figure 2), where each line chart represented a model and in each of them, one could directly compare the value for a particular model output with the mean and standard deviation of the sample. From experts' subjective feedback, we found that they were convinced that this would be an exemplary visualization that could potentially replace the spaghetti plot for comparing temporal variation of multiple model outputs.

Discrepancy between subjective impressions and objective performance: We conducted a controlled experiment with a large group (47 participants) of climate modelers [4] to study the degree to which the familiarity heuristic affects objective task performance and also analyze if there are discrepancies between subjective impressions like perceived confidence, accuracy, etc. and objective accuracy. We selected four visualizations, three familiar ones (heat map, bar chart and Taylor plot) and an unfamiliar one (slope plot), that were most suited to similarity and dissimilarity analysis tasks. The unfamiliar visualization was developed through a participatory design process with two experts for resolving the shortcomings of the familiar visualizations with respect to simultaneous comparison across many (> 10) models and output variables.

We recorded prior levels of experts' familiarity with each of those visualizations and after the study, recorded their preferences and perceived levels of comfort, accuracy, etc. Besides an objective accuracy metric, we devised a *discrepancy* metric that measured the difference in rank orderings of the four visualizations based on their accuracy and based on their subjective ratings of familiarity, preference, etc. This lets us gauge if experts were more accurate with a familiar visualization and also if their preference and accuracy rankings matched.

Overall, we found that perceptually motivated visualization design was a bigger driver for objective accuracy with and subjective preference for a particular visualization. In fact, in the case of a dissimilarity analysis task, the sub-optimal design of the familiar

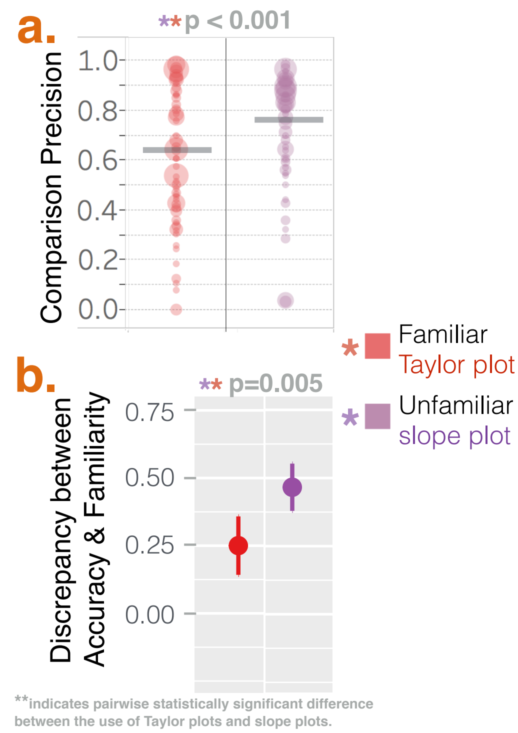

Figure 3: **Familiarity Vs Task Accuracy.** We found that for the task of identifying dissimilar climate models, experts were more accurate with the relatively unfamiliar slope plots than the more familiar Taylor plots. In a) we show the differences in objective performance accuracy. In b) we show the discrepancy between rankings of visualizations derived from self-assigned familiarity scores and the rankings based on performance accuracy. We found statistically significant differences in both a. and b.

Taylor plots caused experts to be less accurate with them than when the used unfamiliar visualizations like slope plots (Figure 3a), where explicit visual cues for similarity and dissimilarity were encoded. Discrepancies could be observed between accuracy and familiarity rankings: experts, across high and low experience groups, being more accurate with a less familiar visualization (Figure 3b). Experts were also most accurate with their preferred visualization. The difference in preference levels for an unfamiliar visualization as opposed to a familiar one was less pronounced for participants with higher experience levels. From the subjective feedback of participants, we also found comments approving of the unfamiliar slope plots and their inclination to adopt them as part of their own analysis workflow.

4 Critical Reflection

In this section we summarize and reflect on the research questions that can be formulated based on the work discussed here. While some of the studies discussed here addressed these questions, they by no means provide a complete picture of the factors associated with familiarity related cognitive biases.

Does familiarity affect subjective impressions about visualization based judgments? From all the studies discussed here, we do find evidence to believe that the familiarity heuristic has a strong effect on the preference for use of conventional visualizations by domain experts. However, participatory design sessions have proved to mitigate this effect [3].

Carefully conducted experiments, where experts have to conduct a set of tasks in controlled settings, have also been able to reduce the bias and indicate preferences in favor of the new, perceptually motivated visualizations. The reduction of bias was less prominent, however, for more experienced people who are potentially more hesitant in using and trusting the outcome of new analysis methods.

Does familiarity lead to better task performance? In our studies, we have used familiar visualizations which have been hypothesized to have certain shortcomings with respect to visualization design principles. In those cases, familiarity did not lead to a better performance. In fact in most cases, experts performed better with the unfamiliar visualizations, irrespective of their length of domain experience due to their perceptually optimal design. In the future, it will be interesting to compare familiar visualization techniques and systems with no shortcomings to unfamiliar ones to assess how strongly familiarity alone biases the judgment of experts.

How can biases associated with familiarity be measured? We used the discrepancy metric to understand how strongly the familiarity heuristic influences differences between perceived and objective performance measures. Metrics like persuasion [11] can also be used to evaluate if experts can be persuaded to not underestimate the detrimental effects of design problems. In cases where ground truth for expert judgments is unavailable, we can use a consensus metric to see if groups of experts agree or disagree about the decisions made based on visual evidence and understand the effects of the bias on population samples.

What are the implications for visualization adoption? A key decision for experts when performing their analysis is which visualization technique to use to address their tasks. As discussed earlier, the familiarity heuristic is a key determinant for this decision. While small case studies are able to demonstrate the effectiveness of new techniques, these are inadequate to change the lack of self-efficacy associated with adoption of new techniques. Interactive visualization techniques in many cases are disruptive for a domain. Sustained research collaborations are needed for longer term adoption of such unfamiliar techniques and new metrics and studies need to be developed to judge the factors responsible for expert adoption [13].

5 Conclusion

In this paper, we have provided a descriptive analysis of the strong role that the familiarity heuristic plays in experts' judgments using visualizations. The main problem with the familiarity heuristic is that it causes experts to subconsciously rely more on the conventional methods that might lead to sub-optimal performance. However, we have shown that though participatory design that carefully considers both experts' requirements and visualization design principles, we are not only able to inspire greater levels of experts' subjective preference in the alternative unfamiliar methods, but also find demonstrable evidence where perceptually motivated design can minimize the effect of familiarity by leading to greater performance accuracy.

These are still early research efforts in the direction of understanding biases related to familiarity. To make the use of visualization a viable and lasting solution for domain experts, we need to pursue the outlined research questions and work together towards efforts that lead to long-term adoption of *the best practices in* visualization methods and techniques.

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