[You have done a within-subject comparative study with the following measures:
- task time
- error rate
- subjective assessment (NASA TLX, SUS)]

Chapter 6

User Study Design

6.1 Introduction

Uncertainty visualisation is one of the complex tasks in visualisation domain, so designing ~~an~~ a ~~efficient~~ user study is also ~~significantly~~ important ~~job to conduct the study smoothly and attain expected result~~. The study design usually prepares a particular set of questions that depends on the nature of the research, goal of the research, and the availability of resources, etc. There are various types of user studies such as experimental/interventional studies, descriptive studies, observational studies, and so on. Since our research domain is in visualisation, we have chosen interventional study design pattern. Interventional studies are experiments where the researcher actively performs an intervention to one, more or all members of a group of participants based on the nature of the study.

Valid

[Reference: Lam et al. 2012, IEEE Transactions on Visualization and Graphics]

[This is for medical research]

[read this paper]

6.2 Background and Goal

We have implemented a novel approach of uncertainty visualization and uncertainty data is generated from some existing machine learning predictive models. We then visualise the data itself in web platform in terms of Chromatic Aberration in an interactive fashion. This simulated Chromatic Aberration (CA) ~~is~~ artificially separated ~~by~~ the Red, Green, and Blue components of colors spatially around visualisation elements such as squares and circles. The effect is a particular kind of blurriness of color perception. The idea is that the more uncertainty there is in a single predicted datapoint, the more its visual representation will be affected at its outer edge by this artificial chromatic aberration, with the intent of conveying that sense of uncertainty to the viewer through the visual channel.

The purpose of this study is the test whether in fact chromatic aberration can be used successfully to represent uncertainty and determine how accurately viewers can estimate the degree of uncertainty based on a given level of chromatic aberration applied to representative visual elements of predicted data values. This will be determined interactively with users through a web-based visualization system. We have found a publication Correll et al. [35] that also visualises uncertainty ~~at their own way~~ called Value-Suppressing Uncertainty Palettes (VSUP). So, the prime goal of this study is to compare ~~of~~ chromatic aberration with that existing approach, VSUP.

in an alternate fashion

6.3 Research Questions

For our research, we have ~~few~~ research questions:

1. How Visualising Uncertainty with Chromatic Aberration ~~works in web platform~~ compared to VSUP in terms of user perception and detection accuracy?
2. ~~Which representation is better among circular and square?~~
3. ~~Which one works better for single vs double variable representations?~~
4. Which representation is ~~faster~~ in terms of user ~~perception and~~ response?
5. ~~Which representation works better with Shapiro-Wilk normality test(t-test) [68]~~?

6.4 Study Material

We have developed a dynamic webpage with the content of study materials to ~~seamlessly~~ conduct the study session entirely remotely ~~through~~ online. It helped to save both participant's and researcher's travelling time to meet in a common place and eliminate the risk of health issues due pandemic. That's why it was mandatory for each participant to have a Computer/Laptop and ~~speedy~~ enough internet connection to share participant's screen and uninterrupted audio conversation.

6.4.1 Technology and Browser

The webpage is developed with HTML, CSS, JavaScript, and D3.js for frontend and PHP in backend, deployed in the webspace (web.cs.dal.ca) allocated to the student by the Department of Computer Science, Dalhousie University. Since the webspace has public access over internet, anyone could access the page from anywhere ~~and it inspired us to design the online study~~ which helped to remain inside the COVID-19 safety guidelines defined by the Nova Scotia Health department and provincial authority.

~~We~~ have used CSS color blending to represent Chromatic Aberration that does not work properly in Google Chrome/ Safari. ~~We noticed they can't~~ render the blended color properly and ~~even~~ when there are large number of cells with color blending in a chart, Chrome crashes. ~~As~~ we found Firefox and Microsoft Edge works ~~perfectly~~ and ~~it serves~~ our purpose, ~~we didn't dig into detail about browser issue since multi-browser support was not our concern~~ and Firefox/Edge are easy to install ~~in~~ any computer having an internet connection. For this reason, we made either Firefox/Edge mandatory for the participation.

6.4.2 Components

As already noted, VSUP is the closest publication that also presented another technique of uncertainty visualisation but that uses only grid-chart representation. In other words, the smallest unit of their representation is square shape. But in our representation, we introduced both circles and squares and that's why we created the following core components of our study:

- **CA + Bubble**: Chromatic Aberration is applied on circles in a bubble chart.
- **CA + Grid**: Chromatic Aberration is applied on squares in a grid chart.
- **VSUP + Bubble**: Uncertainties are presented with circular shapes.
- **VSUP + Grid**: Uncertainties are presented with square shapes.

So, first two components use CA and the last two use VSUP representation. In other words, two representations are implemented in four different components with slightly modified approaches.

6.4.3 Counter Balancing

Each component consists of eight questions. The order of the questions is selected randomly that means no two participants would get the questions in same order and the components itself were presented to the participant in "Balanced Latin Squares" method of counter balancing mechanism proposed by I. Scott MacKenzie [67] to give equal emphasis to each component throughout the study and balancing the learning effect. We have explained in detail about the study procedure in Appendix-E but for easier understanding here is given an example of balanced-latin-square.

A	B	C	D
B	C	D	A
C	D	A	B
D	A	B	C

A	B	D	C
B	C	A	D
C	D	B	A
D	A	C	B

Figure 6.1: Latin Square (left), Balanced Latin Square (right)

If we consider four components as A, B, C, and D then first participant will in order of first row, second participant will get order of second row and fifth participant again will get order of first row again. This approach ensures, no two consecutive participants will get same order of components and finally 8 participants among 32 will get each component at first place.

Most empirical evaluations of input devices or interaction techniques are comparative. A new device or technique is compared against alternative devices or techniques. There are two common designs for such experiments *within-subjects design* and *between-subjects design*. We have used earlier one because we needed to test every component of the system by every participant.

Counterbalancing conditions using a Latin Square does not fully eliminate the learning effect noted earlier. Note in Figure 6.1 (left), the 4 × 4 latin square design, component A follows component B for three of the four groups of participants. Thus, there is a tendency for better performance on component B simply because most participants benefited from practice on Component A prior to testing on Component B. This phenomenon is eliminated using a *balanced Latin Square* Figure 6.1 (right).

6.5 Recruitment

Since the participants play one of the key roles in any user study, it's very important to find the suitable participants for the study based on the attributed research domain.

As we have four independent components in our study and each component has eight random questions, we decided to hire (4 x 8 = 32) participants to give equal emphasis to every component and questions. The detail procedure and considerations about recruitment are described elaborately in the following sub-sections.

6.5.1 Criteria

The population for our study is open for all over the world including members of the Dalhousie University community. We also require participants to be fluent in English because there are questionnaires which needs to be understood correctly and answer accordingly. They all are at least post-secondary students or professionals who have some degree of computer experience as a user of common computer applications. So, here is the checklist of the criteria:

- **Age**: We wanted to eliminate participant of age lower than 17 years and higher than 60 years. Because younger participant might not have sufficient knowledge to understand the scope of the questions and elderly people might suffer from eyesight issues. For the elderly, we allowed exception by going through Color Blindness Test explained in 6.4.
- **Education**: We considered minimum education level must be post-secondary level to get the insight of the questions.
- **Experience**: We do not require any expertise in specific domain but need to have minimum expertise in computer uses, browsing websites, understanding geometric shapes like circle, squares, grid, bubble chart, detecting thickness or borders, identification of colors, etc.
- **Vision**: Participant's eyesight must be reasonable to detect objects and pass through our color blindness test to participate in the study,
- **Head Mobility**: People who suffers from brain disorder or loses their deterministic ability are not considered for the study.
- **Physical Ability**: Participant must not be disabled to use the keyboard, mouse, browse the web and in a word using computer. They must have fingers to use keyboard and mouse.
- **Computer**: Must own a computer/laptop for the period of study session. Smartphones are not accepted to participate in the study due to the insufficient display size.
- **Internet**: Must have a good internet connection to continue the session without interruption in voice and video(screen) sharing. Participants of rural areas where internet connections are vulnerable are discouraged to participate.

6.5.2 Hiring Procedure

In modern world, Internet is relatively cheaper and easily accessible almost all over the world. So, we preferred to use online publicity of recruitment strategy. We sent a recruitment notice to the Dalhousie University Computer Science undergraduate and graduate mailing list, Dalhousie Computer Science jobs email, physical bulletin boards on campus, in my social media wall. The recruitment notice outlined the study (process, eligibility criteria, data collection, compensation, and estimated time requirement) and instructions to contact the main researcher. Once a potential participant shown interest with reply email, the main researcher emailed them a with more detail information and attached a consent form for their perusal and suggested to reply with three potential time slots if they agree with the detail requirements and a consent form content. Participation acceptance was done on a first-come first-serve basis until all places were booked, but to be in safe side we kept some additional participants in waiting

~~list~~. When participants either became sick or cancelled or did not continue interest up to the sessions, potential wait-list participants were called serially as per their time of participation confirmation.

6.5.3 Making Schedule

On confirmation of participation interest by participant, main researcher created an MS Teams/Skype event with the agreed time. Participants ~~got~~ a notification in their inbox with the detail of the event including a ~~join~~ URL to the event. At the meeting time participant just needed to open the link in either browser or installed desktop application of the relevant tool to start the session.

Main researcher used a MS Word document as logbook to manage, track and keep the study process synchronized. Researcher always ensured that two participants participation time could not overlap each other and tried to keep a gap of 30 minutes between two schedules so that unexpected ~~prolonging~~ could be mitigated by that buffer time.

6.6 Study Procedure

The study session contains several stages such as color blindness test, modular sessions for each of core components, module introduction and clarification before starting a module, and post-session questionnaires ~~clarification~~ after completing core modules. In the following section we explain them briefly.

6.6.1 Start Event

Since the study ~~is decided to~~ conduct online and schedules ~~are~~ made between two parties (researcher and participant) and an event is created through the online meeting platform or conferencing tool such as MS Teams, the participant just needed to be in front of a computer at scheduled time of the day and click on the link he or she received in his or her email to meet in the meeting platform. When the participant ~~log-in~~ to the system, it will ~~notify~~ researcher that participant is waiting at the lobby, and he needs to ~~admit~~. On approval, the event is instantly started ~~at~~ the online meeting room and both parties will be able to hear each other. Researcher greeted and welcomed the participant and ~~participants also~~ exchanged their formal greetings. If participant faces any technical difficulty to join then researcher tried to help by possible means.

6.6.2 Briefing

The researcher needed to brief the participant about the steps he or she had to go through and explained how he was going to conduct the session. Participant were also asked if his/her system has Firefox/Edge browser installed which is mandatory for the study. If not he/she would be requested to install it and researcher might instruct if needed any help regarding the installation of the browser. After confirming the browser is ready to go with, participant is requested to open it and informed him/her that researcher would give two URLs for the session i. for Color Blindness Test and ii. for Questionnaire about the study.

6.6.3 Color Blindness Test

One of the prime requirements for the selection process is to test for color-blindness of the participants. The participants had to be capable to decern color to provide meaningful input through their participation in the study. To maintain similarity with Correll et al. [35], we presented a set of Ishihara plates [60] attached in Appendix E in a webpage. URL of the page (Figure 6.1 shows a screenshot of the webform with plate and input fields) is given to the participant through chat(conversation) box of the conference tool and requested to fill the input field with what they saw in the image and click next to get next question. This would continue until it ended with all samples provided. We excluded those that misidentified values or who self-reported as having a color vision deficiency.

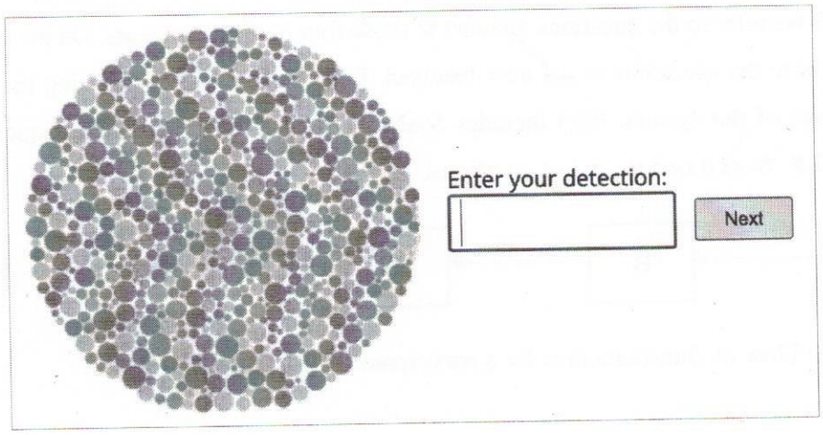


Figure 6.2: Example Color Plate in our portal

6.6.4 Pre-Session Discussion

After color blindness test passed successfully, researcher asked participants about some basic questions which we thought to be relevant with their performance. Because it needs full concentration on the task to understand the question, find relevant values, uncertainties/CA, and eventually perform better. For instance, the following information are noted down by the main researcher:

- Educational (science, arts, etc.) background
- Professional background (IT, Accountant, etc.)
- Computer skills (Basic, Intermediate, Expert)
- Mathematical and Geometric knowledge
- Visualization and Computer graphics knowledge
- Computer gaming skill
- Measurement knowledge (inch, feet, pixel, etc.)
- Physical Condition (Tired, Sleepy, Hungry, Fresh, etc.)

6.6.5 Questionnaire

There were two types of questions in our user study design, and they are as follows:

i. Component Questions
ii. Post Session Questionnaire (PSQ)

As noted previously in 6.2.2, we have four components in our study. So, by Component Questions we refer to the questions relevant to those four core components. On the other hand, PSQ refers to the questions to get user feedback from the experience of using the four core components of the system. PSQ includes System Usability Scale (SUS) test questions and NASA-TLX Work-Load Scale test questions.

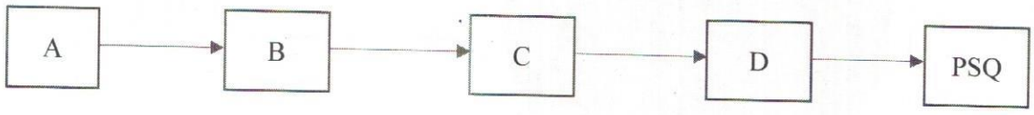


Figure 6.3: Flow of Questionnaires for a participant

If we consider A, B, C, and D as four components of the study then Figure 6.3 shows the flow of the components that come one after another randomly during the session of the participants as discussed in counter-balancing section. It also shows that PSQ appears at the completion of four modules. We know, our four core components are inspiration of two basic representations

CA and VSUP as we discussed earlier in section 6.4.2. That's why PSQ section contain questions regarding the groups CA and VSUP.

We intentionally placed PSQ at the end of core modules so that participants could give their fair ratings based on their immediate experiences gathered from the components. Since we have used our self-developed online web page to conduct the whole session, the system automatically and quantitatively captures the participant's answers and saves in memory time to time and stores in the server at the end of the study. Figure 6.4 shows System Usability Scale test related question sample for both CA and VSUP.

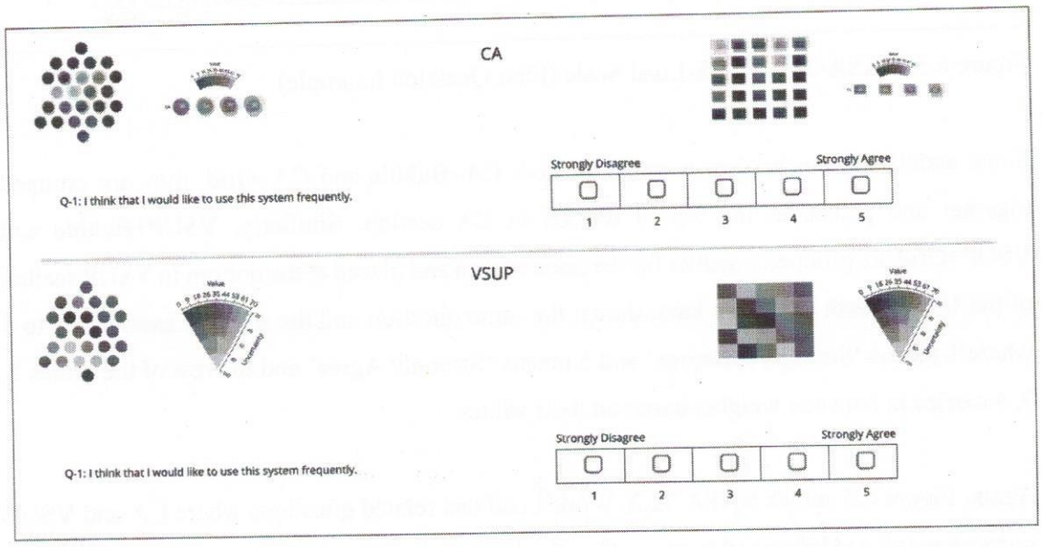


Figure 6.4: System Usability Scale (First Question Example)

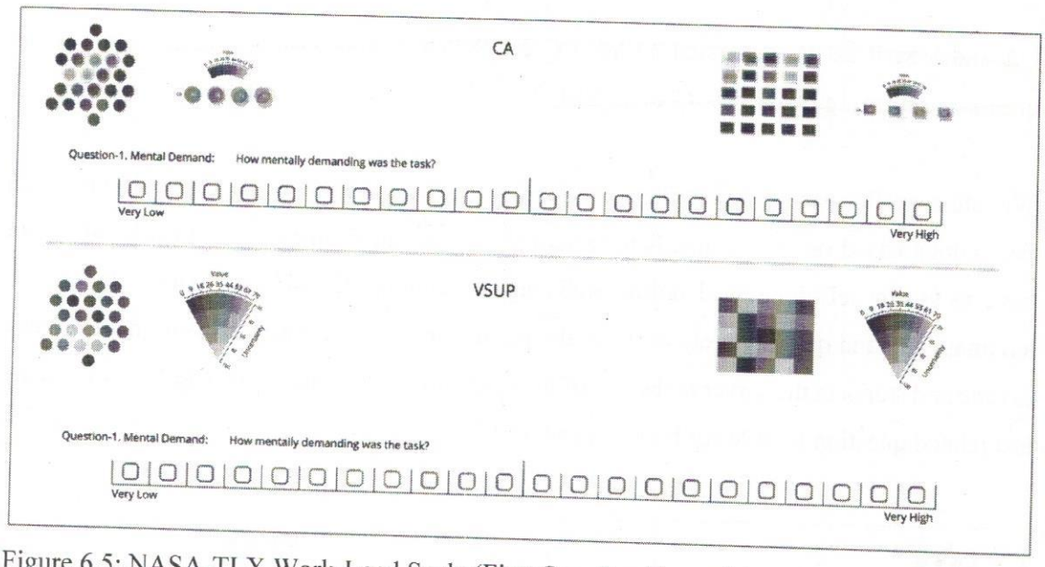


Figure 6.5: NASA-TLX Work-Load Scale (First Question Example)

Since underlying mechanism is same for both CA+Bubble and CA+Grid, they are grouped together and placed at the top of the UI in CA section. Similarly, VSUP+Bubble and VSUP+Grid are grouped together for the same reason and placed at the bottom in VSUP section of the UI. For both cases, we have shown the same question and the scale of answer is 1 to 5 where 1 means 'Strongly Disagree' and 5 means 'Strongly Agree' and the rest of the scales 2, 3, 4 carries in between weights based on their values.

Again, Figure 6.5 shows NASA-TLX Work-Load test related questions where CA and VSUP sections are placed in top and bottom respectively since they are two groups of four components just like SUS test explained in previous section. But in this case the number of questions is six and the scale range is 1(Very Low) to 22 (Very High).

We have not shown all questions here for ~~none of~~ SUS or NASA-TLX as we mentioned the complete list in APPENDIX E.

We can summarise the questionnaire as follows:

- Each component would appear to the participant conforming counter balancing rule as stated in 6.4.3.
- Every component had eight random ordered questions but the content of the question for every participant were same.

- Post Session Questionnaire had two types of questions i. SUS and ii. NASA-TLX
- SUS had 10 questions and NASA-TLX has 6 questions.
- Total number of questions = 4 x 8 + 2 (10 + 6) = 64

6.7 Data Collection and Storing

We have developed the webpage by ourselves, so we have implemented it in such a way that system can automatically track status of every answer whether correct or wrong. That means it keeps record of every question from starting to end in a JSON object. The structure of the sample JSON data is given below:

```
Data = {
  ca-bubble: {
    Q1: {      // single variable and single target selection
      status: true,
      ca: 52,
      mode: "single-var-one",
      selected: ['Vietnam'],
      options: ['Vietnam', 'Canada', 'Philippines', 'Kazakhstan', 'Palestine', 'Colombia']
    },
    ...
    Q3: {      // single variable and all target selection
      status: true,
      ca: 90,
      mode: "single-var-all ",
      selected: ['Mongolia', 'Argentina', 'Russia', 'Peru'],
      options: ['Argentina', 'Mongolia', 'Peru', 'Russia']
    },
    ...
    Q8: {    // double variable with single target selection
      status: true,
      ca: 71,
      mode: "double-var ",
      selected: ['Peru'],
      options: ['Mongolia', 'Peru']
    },
    single-var-one-time: 4.9,  // time required for questions of single variable-single answer
    single-var-all-time: 5.7,  // time required for questions of single variable-all answers
    double-var-time: 6.5  // time required for questions of double variable-single answer
  },
  ca-grid: {... same structure of ca-bubble  ...},
  vsup-bubble: {...  same structure of ca-bubble ...},
```

vsup-grid: {... same structure of ca-bubble ....},

nasa-ca: {1: 14, 2: 13, 3: 14, 4: 15, 5: 15, 6: 15}, // answers of NASA-TLX for CA components

nasa-vsup: {1: 13, 2: 12, 3: 13, 4: 12, 5: 13, 6: 12}, // answers of NASA-TLX for VSUP components

sus-ca: {1: 2, 2: 3, 3: 4, 4: 3, 5: 4, 6: 3, 7: 2, 8: 3, 9: 2, 10: 3}, // answers of SUS for CA components

sus-vsup: {1: 2, 2: 1, 3: 2, 4: 1, 5: 2, 6: 3, 7: 2, 8: 3, 9: 2, 10: 3} // answers of SUS for VSUP components

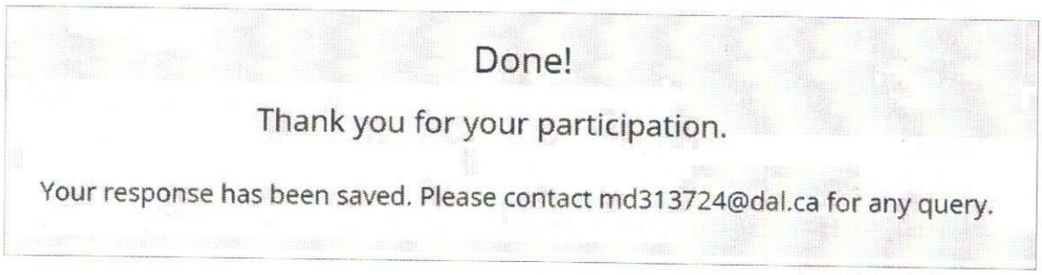
}

}

After completion of entire questionnaire, the generated JSON data is stored in server with the email address provided by the participant. In the above sample structure, we see for every component it has its own block with the common set of properties for each. The above structure is designed with some self-descriptive properties that it would be helpful later in results and numerical analysis phase.

6.8 Session Ending

Once the participant completed the post-session questionnaire, the page immediately informs the participant with following message:



Finally, participants were given whole-hearted thank for their dedication and participation in the study and immediately send the promised $10 e-gift card (Amazon) to their email address. A sample of such gift card is attached in APPENDIX K.

Amazon gift-card, will be added in APPENDIX K in main document.

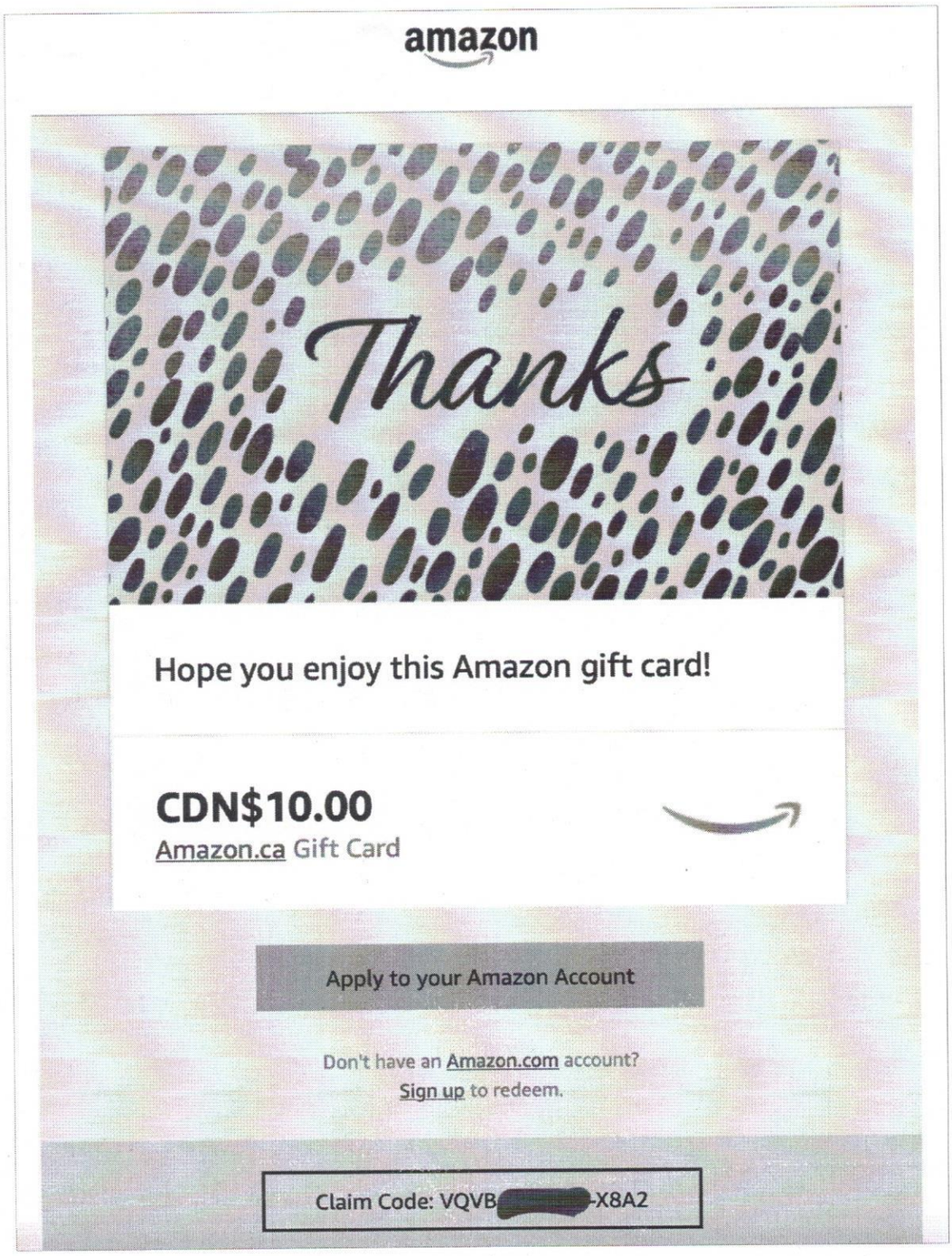


Figure K.1: Amazon gift-card (Claim Code ~~Impaired~~ since it is sent to the participant)

redacted.

Your comment was:

2.6 Evaluation of Visualization Systems (see papers such as "Empirical Studies in Information Visualization: Seven Scenarios" as well as the papers it references and the papers that reference it)

2.6 Evaluation of Visualization Systems

Visualization evaluation is a complex task since it involves complex data structures or patterns, or it can exhibit various interconnected information ~~of complicated systems~~. Researchers and practitioners in this field have faced many challenges in different phases when designing, planning, conducting, and executing an evaluation of a visualization systems. It can be a difficult task for ~~a~~ evaluator to design ~~the~~ suitable evaluation questions to ask the participants, to pick the right variables from visualization artifacts, to decide and develop an efficient way to test data sets and pick the proper methods of evaluation. Existing literature guidelines can help to solve these problems for example, Heidi et al. [64] ~~came up~~ with seven scenarios of information visualisation from their research that includes evaluating visual data analysis and reasoning, evaluating user performance, evaluating user experience, evaluating environments and work practices, evaluating communication through visualisation, evaluating visualisation algorithms, and evaluating collaborative data analysis. They suggest different approaches to reaching decisions about what could be most effective evaluation of a given visualisation system. Among them some of them are related our study, so we briefly discuss about those in the following section.

detailed.

User Performance

User performance is mainly measured in terms of objectively measurable metrics such as time, error or accuracy rate, or work quality but the task completion time or task completion accuracy is commonly used. Output of the tasks are generally numerical values analyzed using descriptive statistics such as mean, median or standard deviations. They can also come from the user interactions, perception, and cognition for specific types of visually presented techniques. Most widely used methods are ~~the~~ controlled experiments or quantitative evaluation. A controlled experiment requires real-life ~~simple~~ tasks that can be performed by large number of participants in different study sessions. It is not imperative the participants ~~to~~ be domain experts, hence non-experts can also participate in such experiments. To answer evaluation questions with quantitative and statistically significant results, evaluations in the user performance group require high precision. The commonly used methodologies involve an

that.

experimental design with only a small number of variables changed between experiment conditions such that the impact of each variable can be measured J. McGrath [66].

User Experience

Evaluation of user experience is done by ~~study people~~'s subjective feedback and opinions in written, spoken form or online feedback with a set common questionnaire to all participants. It seeks to understand how participant react to the presented visualisation. A visualisation can be an initial design sketch, a basic prototype, a finished product, or part of a complex system. The goal is to understand what extent the participants' ~~eyes~~ can perceive the intended ~~tasks~~ conveyed by the system such as perceived effectiveness, perceived efficiency, perceived accuracy. Other measures such as satisfaction, trust, features liked/disliked, effort required, time required, etc. The collected data in such a study helps designers to explore gaps and limitations in the visualised system, as well as promote the researchers to take necessary steps to enhance it further stage. So, the evaluations can be short term to assess current or potential usage and long term to assess the adoption of a visualization in a real usage scenario.

Usability Test

How participants perform a set of predefined tasks is observed to carry out the usability test. For each session, the evaluators take notes of interesting observed behaviors, suggestions given, comments provided by the participant, lack of understanding, and major problems in interaction. The ~~specialities~~ of this method are the careful preparation of tasks and feedback material like questionnaires and interview scripts. Its main goal is to ~~perfect~~ the design by spotting major flaws and deficiencies in existing prototypes [65]. Nonetheless it can also serve the purpose of eliciting overlooked or missing requirements.

Heidi et al. [64] classified the scenarios into two broad categories called *process* and *visualisation*. The main goal of process group evaluation is to understand the underlying process and the roles played by the visualisations. In contrast, evaluations can focus on the visualisation itself, with the goal to test design decision, explore a design space, benchmark against existing systems, or to discover usability issues. Again Bonneau et al. [16] classified the types of evaluation into three groups:

- Theoretical evaluation: the method is analyzed to see if it follows established graphical design principles,
- Low-level visual evaluation: a psychometric visual user study is performed to evaluate low-level visual effects of the method,
- Task oriented user study: a cognitive, task-based user study is conducted to assess the efficiency or the usability of the method.

Usually in these evaluations, a part of the visualisation system is tested. In this context, we intend to evaluate only the basic concept of Chromatic Aberration against VSUP [35] although we implemented and utilized them in some complex charts. To evaluate user experience and performance with the help of a set of questionnaires, we developed an online webpage containing the relevant exercises of visualisation. Instead of asking questions as interviews, we presented everything visually (explained in study design section in chapter 6), so that participants can provide their rating easily. For Example: in system usability test, we presented 10 questions in 5 scale ratings (1-5) and for Nasa-Tlx we presented 6 questions in 22 scale ratings (1-22).

2.7 Limitations of related works

As stated in the related works section, a plethora of studies have been conducted in these domains, for example: predicting modeling and augmentation of algorithms, time series analyses and comparisons on different diseases and/or on other temporal data, real time predictions from models, measuring chromatic aberration from image distortion, effect of color and light on display devices, uncertainty visualization and decision making, texture analyses and assessments, perceptual textures to represent multi-dimensional dataset, and etc. In our knowledge predictive uncertainty has not been represented with chromatic aberration. Furthermore, our approach of three dynamic variables visualization in two-dimensional space with texture is also a novel idea. In the following section we briefly explain specific limitations of some papers listed in the references. (You reviewed this paragraph earlier)

Your comment was:

(in addition to this section that summarizes limitations, you should also briefly note the limitations of each prior work as you discuss them in sections 2.1 to 2.5)

Muhammad Ali et al [2] conducted their research of forecasting COVID-19 only with statistical ARIMA model where they suspect it may perform poorly in case of nonlinear trends. Researchers in [1, 4, 6] used different versions of ARIMA such as ARMA, SARIMA, PROPHET models to conduct time series analysis but have not used any machine learning or deep learning algorithms to compare with. In [5] researchers have formulated a best model of XGBoost machine learning algorithm for cholera epidemics predictions linked with weather variable, but they have not studied with real world data from health-care systems. Climate change with dengue epidemic, a predictive modeling [7] was conducted and concluded that neural network models (MLP, LSTM, GRU) significantly outperforms traditional machine learning models but they have not given analysis background reasoning and no indication of if they tried with optimal hyperparameter settings, since they play key role in such modeling. A decision-supporting tool [8] for medical centers and health-care services has been proposed for influenza prediction with limited data for Belgium which could be tested with more sophisticated and diverse dataset and the similar issue noticed in [9] where they conducted their study on performance evaluation of prediction of machine learning models with liver disease by taking some sample data.

Lateral Chromatic Aberration can lead people to misjudge information shown on displays. Researchers of [10] proposed a simple correction method and design guidelines to attain promising results but that is limited to certain eyeglasses and some common objects and didn't extend it real and generalised environment. Color illusions on liquid crystal displays and design guidelines in information visualisation system [11] is investigated with only limited domain experts and kept open the scope for further study of understanding the cause of the colour size illusion effect. Chromatic Aberration occurs due to refractions of each color channel and hence the [11] addresses the use of image warping to reduce this effect but without calibrating the model for different zoom/focus level, displacement, and deformation. Only lateral effect with image warping is considered in a proposed a system [12, 13] to resolve such problems but not considered about longitudinal, geometric or other forms of optical distortions. These uncovered issues are partially resolved by [14, 15] but their rendering mechanism is limited to single light sources, undergoes with rasterization aliasing effect, interaction with painting metaphor and temporal interpolation with event-driven control. Correll el al. [35] directly integrated uncertainty within a shared chart instead of using tooltip/supportive charts with the strategy of

Value Suppressing Uncertainty Palettes but they intentionally suppressing data with high uncertainty which ultimately eliminates complexity.

Since most visualizations do not explicitly represent uncertainty information, Hullman [36] conducted study and came up with suspicious results due to the possibility of biased/unconfident responses from the participants. Through a controlled study, Guo et. al [37] found that users experience more confidence to determine uncertainty values but that requires the participants need to be domain experts. Korporaal et al. [38] conducted study find the effects of uncertainty visualization on Map-Based decision making under time pressure but didn't test with experts like helicopter pilot, limited to a cartographic display, given brief training to participant neglecting diversity of uncertainty. Sensory information is noisy and insufficient to uniquely determine the environment and natural perceptual systems use to cope with systematic uncertainty. [17] shows that subjective uncertainty in this case is connected to objective uncertainty by using their custom noise model which should be tested with more generalised noise models. Probabilistic animation methods [20] have been presented as an effective approach for uncertainty visualization by which an effective expansion of decision-making support can be achieved by physician running the visualization but still that need to be studied in real clinical environment.

Lucchesi et al. [43] presents three approaches to include uncertainty on maps but have not conducted user studies to determine whether the methods effectively communicate uncertainty. To address the conformity of appropriate uncertainty visualisation MacEachren el al. [44] presents two conceptual perspectives but the study does not cover both data and uncertainty at the same symbol and didn't tested the impact of symbol size. Reveiro [45] provides a general overview on uncertainty representations techniques and theoretically evaluate the weakness and strengths of the uncertainty visualizations representations. R. Finger [49] describes utilization of graphical formats to convey uncertainty in a decision-making task but uses of icons with numerical probabilities causes users hesitating and additional assitance. Skeels [53] classified uncertainties by reviewing existing literatures of various domains and came up with a concept of 'layers' of uncertainty but due to complexity it is kept as open task to visualize.

To reduce the computational cost Netzel et al. [22] introduced particle tracing and line integral convolution that are parallelly and independently used on every pixel of texture but coupling

with exponential filter it fails to handle trends appropriately. Texture-based feature tracking technique [23] has been proposed to overcome some limitations of previous relevant studies such as hampering illustration and visualization of dynamic changes, but it has ~~limitation of~~ drifting problem (move in a direction without input). A new technique [24] of utilising the overlay of two different LIC textures to combine the visualization with vector fields but that doesn't support higher dimensions and yet more refined investigation is required to quantify the effectiveness. To avoid color blurring and inconsistencies in such LIC textures, Huang et al. [25] introduced a novel image-space that also mitigates expensive computation, memory cost but suffers with popping artifacts (too far/close viewpoint). A method for the generation of anisotropic sample distributions and interactive rendering of anisotropic Voronoi cell by Kratz et al [26] is not experimented properly for influence of adding noise to the cell boundaries. Weiskopf [27] has proposed a set of guidelines to stimulate a better awareness for the opportunities and problems involved with the perception of moving color stimuli but not well studied the guidelines with miscellaneous applications in visualization and computer graphics. Healey et al. [28] presents a method for combining three texture dimensions height, regularity, and density to form perceptual texture elements (or pexels) but not investigated ~~yet~~ the effectiveness of orientation for encoding information, and the interactions that occur when multiple texture and color dimensions are displayed simultaneously. R.P. Botchen et al. [29] a generic texture-based strategy to visualize uncertainty in time-dependent 2D flow and they think further extension for 3D flow will be a challenging task.