PERFORMANCE OF IMPRESSIONIST VISUALIZATIONS ON MEASURES OF RECOGNITION AND TREND IDENTIFICATION

by

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Abstract

Experimental aesthetics, one of the oldest branches of research psychology, empirically examines what elements of an image associate with beauty and preference. Drawing on this research the current paper hypothesizes that by applying the painterly techniques of impressionist era artists a modern applied problem of information visualization may be addressed, namely how to create effective and aesthetically pleasing depictions of data.

To do so a series of weather maps obtained from the International Panel of Climate Change were rendered into four data visualization styles: industry standard glyphs, and three impressionism inspired styles titled interpretational complexity, indication and detail, and visual complexity. Two separate experiments were then conducted, each aimed at testing a key feature of effective data visualization, image recognition and the ability to communicate data trends. The first experiment found visual complexity visualizations to be comparable to glyphs on a new-old recognition task, and better than the styles interpretational complexity, and indication and detail. The second experiment found that visual complexity visualizations were more effective than glyphs at depicting and communicating data trends to the viewer. Incidental eye tracking data during both experiments suggests that impressionist visualizations were more engaging and aesthetically pleasing than glyphs as evident by a higher fixation count and greater pupil dilation.

Individually experiments 1 and 2 demonstrate that the painterly techniques of visual complexity may be applied to create highly recognizable and communicative data visualizations. Collectively the two experiments support the broader hypothesis that by modelling the knowledge and expertise of artists we may create aesthetically pleasing and functional depictions of data. Following these results the thesis concludes with a discussion of future research and potential limitations, and how the present results relate to aesthetics research more broadly.
Preface

This thesis through two separate experiments demonstrates that impressionist era painterly techniques may be harnessed to create effective data visualizations. My contribution to the project consists of hypotheses generation, research design, data collection, statistical analysis and writing of the current thesis. All research was approved by the Behavioral Research Ethics Board (BREB) at the University of British Columbia (UBC BREB Number H14-00037).
# Table of Contents

Abstract .............................................................................................................................................. ii

Preface ............................................................................................................................................... iii

Table of Contents ................................................................................................................................. iv

List of Figures ....................................................................................................................................... vii

Acknowledgements ............................................................................................................................. viii

Chapter 1: Introduction ......................................................................................................................... 1

1.1 Psychology & Experimental Aesthetics ...................................................................................... 3

1.2 Modern Aesthetics Research .................................................................................................................. 6

1.3 Information Visualization & Aesthetics ............................................................................................... 8

1.4 The Present Study ............................................................................................................................. 9

Chapter 2: Experiment 1 – Recognition ............................................................................................ 14

2.1 Participants ....................................................................................................................................... 14

2.2 Stimuli and Apparatus ..................................................................................................................... 14

2.3 Procedure ......................................................................................................................................... 14

2.4 Statistical Analysis ............................................................................................................................. 16

2.5 Results ............................................................................................................................................... 17

2.6 Discussion ......................................................................................................................................... 18

Chapter 3: Experiment 2 – Trend Identification ................................................................................ 20
List of Figures

Figure 1: Gestalt Principles And Aesthetic Examples................................................................. 28
Figure 2: Glyph Depiction of Weather Map Data................................................................. 29
Figure 3: Impressionist Paintings Associated With Study Visualization Styles......................... 30
Figure 4: Example Glyph, Interpretational Complexity, Indication and Detail, and Visual Complexity Visualizations................................................................................................................. 31
Figure 5: Perceived Complexity and Arousal Ratings............................................................. 32
Figure 6: Memory Performance.................................................................................................. 33
Figure 7: Participants Eye Movements During Subjective Rating............................................. 34
Figure 8: Participants Mean Accuracy for Trend Identification.................................................. 35
Acknowledgements

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Chapter 1: Introduction

A skilled artist is often considered to be one who can fluently evoke a wide range of emotion, without overburdening the viewer, regardless of whether the content of the artwork concerns the human form, detailed landscapes, or more abstract imagery and color. A canvas thus provides opportunity for an artist to apply their knowledge of the human visual system, be it implicit or explicit, and to guide, highlight, engage and orient the viewers’ attention while still creating an aesthetically pleasing artwork. In practise this often leads to certain portions of the artwork being highly detailed, like human faces, while others areas are less detailed, distorted or have unrealistic physics (Cavanagh, 2005). Artists thus seemingly know which shortcuts can be taken, rules of perception broken, and exaggerations made, such that extraneous details are omitted and the viewer still guided toward desired areas of attention (Ramachandran & Hirsten, 1999; Cavanagh, 2005).

Intriguingly what scientists often find within their laboratories, artists have long been exhibiting in their studios. For instance, when asked, individuals often report preferring horizontal and vertical lines over oblique lines (Latto 2004), a preference that many artists, including Piet Mondrian, may have been guided by when creating their artworks (Latto, Brian, Kelly, 2000). Indeed, across art genres, artists have often demonstrated this simple caveat, with paintings often having far greater emphasis of horizontal and vertical lines relative to oblique (Latto & Russell-Duff, 2002). Individuals also generally report preferring smooth contours over sharp contours (Bar & Neta, 2006), and coupled with this are a multitude of artworks renowned for their careful application of curvature (Bertamini, Palumbo, Gheorghes & Galatsidas, 2015), one need only think of Vincent Van Gogh’s 1889 painting The Starry Night for a quick visual. The importance of curvature so well-known that many artists have established rules and guidelines for their application, English painter William Hogarth for instance in his text The
analysis of Beauty (1753) dedicates considerable length in illustrating and describing what constitutes an aesthetically pleasing brushstroke curve and what is otherwise poor and mean.

In addition to identifying features of an artwork associated with beauty, talented artists are often masters of orienting and guiding our attention. Consider that Baroque era painters like Rembrandt and Vermeer seemed to be carefully applying color and textural variations such to accentuate and draw viewer attention toward desired portions of an artwork, very often the eye-region of a depicted individual (DiPaola, Riebe & Enns, 2010). Through such manipulation, paintings and artworks often allow for the creation of an image that is distinct from what would be captured by a photograph or video. Indeed this ability to interact and engage with our perceptual system might be comparable to the knowledge we would expect from a neuroscientist (Zeki & Nash, 1999; Cavanagh, 2005)

In considering these different lines of research, a consensus seems to foster that skilful artists have a unique mastery of the human perceptual system. The current thesis steps out from this claim and then asks if this mastery may be harnessed and applied. As technological innovation continues to foster, complex data sets are becoming more frequent, available in larger quantities and typically are highly multivariate. In making sense of these datasets scientists often rely on visualizations, though creating visualizations that are engaging, informative and aesthetically pleasing is a challenging task. The expertise of artists thus seems particularly well-suited in addressing this qualm and offering potential solutions.

To bring the knowledge of artists into the lab we rendered a series of weather maps into three visualization styles based on the painterly techniques of impressionist era artists. In doing so, we may compare impressionist visualizations to glyph visualizations, which are the current industry standard. Specifically through two separate experiments a comparison may be made
whether relative to glyphs, impressionist visualizations are beneficial for data recognition and trend identification.

Experiment 1 focused on data recognition. Participants viewed and were asked to rate a series of weather map visualizations on their perceived complexity and arousal. After this rating phase, subjects completed a surprise memory test in which they had to identify whether certain visualizations were previously seen or not. In doing so we tested the recognisability of the different visualization styles, and found that the impressionist style titled *visual complexity* performed on par with glyphs. Experiment 2 tested the ability of each visualization style in communicating data trends. Subjects were asked to identify what percentage of a briefly presented visualization was blue, where blue was representative of a particular weather condition (e.g. mean temperature). Results showed that visual complexity was superior to glyphs for this task. Lastly, incidental eye tracking during both experiments revealed that impressionist visualizations were more alluring and aesthetically pleasing relative to glyphs as implicated by a higher fixation count and greater pupil dilation. Combining this set of results, we may conclude that by modeling the painterly techniques of impressionist era artists, visualization styles can be created that are highly memorable, effective for communicating data trends, and foster viewer interest. In accomplishing these aims, the present thesis first embodies and presents the underlying history and academic studies ultimately leading to such a conclusion before phrasing them in a broader research context.

1.1 Psychology & Experimental Aesthetics

The birth of psychology as a scientific discipline can traced back to the early work of, among others, prominent German philosopher and physicist Gustav Fechner (Hawkins, 2011). Perhaps his largest contribution to psychology was the development of psychophysics, an
approach to studying psychological experience in which subjects report their sensations and perceptions of quantifiable physical stimuli. For instance, subjects might be asked to place an item into their left hand, and then asked if a subsequent item placed into their right hand is of equal, lesser, or greater weight. Not limited solely to weight, similar studies were conducted using with visual distance, tactical distance, and luminance estimations (Schultz & Schultz, 2011). In addition to developing this approach of psychological study, Fechner further influenced the field by fathering experimental aesthetics, a subfield of psychology that seeks to empirically study, identify, and understand features of beauty and preference (Fechner, 1876).

Among Fechner’s research in experimental aesthetics was an effort to find the ideal rectangle ratio perceived to be most aesthetically pleasing, which his participants generally identified as being 34 to 21, or 1.619. Often referred to as the golden ratio, patterns of this value are frequently reported within nature including snail shells and flower petals (Livio, 2008), as well as numerous famous artworks like the Mona Lisa by Leonardo Da Vinci (1503–1506) and The Sacrament of the Last Supper by Salvodor Dali (1955). Though intriguing with a broad diversity of claims, such reports of the golden ratio are also often paired with controversy (Falbo, 2005; Markowsky, 1992).

Though Fechner provided an ambitious start, experimental aesthetics fell into a lull shortly after the formal birth of psychology, as the field grew increasingly dominated by the approach and methodology of behaviourism (Martindale, 2007). Given the preference of measuring overt explicit behaviours and actions, behaviourists had little taste or vigour for aesthetics research which frequently relied on participant’s subjective reports or judgements of various stimuli (Leder, 2013). Though this is not to say findings relevant to experimental aesthetics were entirely begotten, as could be found within the soon blossoming field of Gestalt
psychology. Differing from their behaviourist colleagues, Gestalt psychologists sought to outline the rules and principles of human perception. Much of their research bolstered the rule that the sum is more than the mere parts, that a group of stimuli when perceived piece by piece might amount to nothing exceptional, but, when these same pieces are perceived collectively they amounted to something far greater. Countless images and examples that underlie this point may now be found in modern psychology textbooks, each serving to enlighten and educate the viewer about the human perceptual system, while similarly being highly entertaining (Rock & Palmer, 1990; Koffka, 2013).

Two such images are presented in the upper half of figure 1, the left image (a) depicts the principle of multistability. Consider that by simply re-directing our attention of this image, the form we perceive may either be a vase or two faces in profile. The second image on the upper right (b) depicts the principle of similarity. Often as viewers we pair together stimuli that share certain visual properties with one another, and in this particular case, that the black circles form a single horizontal collective below which is a horizontal collective of white circles and after which the pattern repeats. As these principles of human perception were being studied by psychologists, numerous artists had arguably long since been applying and manipulating them within their studios. An illustration of how artists might use such principles of perception can be found in the lower half of figure 1. In the lower left corner (c) is a painting by the surrealist artist Salvador Dali titled Apparition of Face and Fruit Dish on a Beach (1938) in which the central image may be viewed as either a face or chalice depending on how attention is allocated. Image (d) on the other hand is a woodcut print titled Sky and Water I (1938) by artist Maurits Escher in which rows of strikingly similar birds gradually shift into rows of fish. Such artworks would
seemingly be as welcome inside an artist’s studio, as a lecture on perception within a psychology course.

Though a somewhat turbulent time for the subfield, research in experimental aesthetics once more arose in the 1950 and 60’s following the cognitive revolution and decline of strict behaviourism. Such a paradigm shift coupled closely with fervour and passion saw topics of mental phenomena and subjective experience once more take central stage (Miller 2003; Schultz & Schultz, 2011). Perhaps no researcher however helped bring aesthetics back into the laboratory as prominently as Daniel Berylne (1971, 1974) who is often referred to as father of “new experimental aesthetics.” While much of his research still favoured the methodology of the behaviourists before him, many of his insights including the importance of arousal and complexity in aesthetic experience continue to reverberate within the field today.

1.2 Modern Aesthetics Research

Modern aesthetics research today might roughly be divided into two broad camps. The first and perhaps more rooted in history, measures and manipulates features of the stimulus itself and how this corresponds to viewer perception. For instance individuals report symmetrical images as being more beautiful than less symmetrical images (Jacobsen & Hofel, 2002), prefer horizontal and vertical lines over oblique lines (Latto, Brian, Kelly, 2000; Latto 2004; Johnson, Muday & Schirillo, 2010), and curved contours over sharp contours (Bar & Neta, 2006). The second approach, and arguably more modern, considers the unique attributes and characteristics of the viewer and how these tie into aesthetic experience. Examples of such research include findings that that men prefer more saturated and active colors relative to women (Palmer & Schloss, 2010), that individuals high on sensation seeking prefer surreal art over representational
art (Furnham & Avison, 1997), and that art majors prefer high art while non-art majors prefer popular art and rate it as being more pleasant and warm (Winston & Cupchik, 1992).

A scientist however need not be an artist to notice a clear link between their work and the art community. Numerous studies for instance have found that individuals prefer horizontal and vertical lines over oblique lines, and in light of this Latto & Russell-Duff (2002) considered a large catalogue of 20th century paintings and found that for both landscapes and portraits, artists across a wide variety of styles and categories heavily preferred the use of vertical and horizontal lines over oblique lines. Whether these acclaimed artists were explicitly aware of this, were self-taught or attended art school, they regardless seemed to be tapping into a broadly reported aesthetic preference. The importance of curvature may serve as another guiding point, as individuals often exhibit a preference for smooth contours over sharp contours (Bar & Neeta, 2006). Though this finding is relatively recent, artists have long since been discussing the importance of curvature within their artworks. English painter William Hogarth for instance illustrated and wrote on curvature in his text *The analysis of Beauty* (1753), and provided examples for what constitutes an optimally pleasing curve. Numerous other artists also held beliefs and followed particular guidelines concerning curvature, with many resulting artworks since becoming renowned for their particularly attractive application (Bertamini, Palumbo, Gheorghes & Galatsidas, 2015).

The brushstroke curvature of Vincent Van Gogh for instance serves almost akin to a signature in defining his artistic style. Indeed, Van Gogh intentionally accentuated certain portions of his artworks which he thought particularly important, writing to his brother Theo that “I am trying now to exaggerate the essential, and purposely leave the obvious things vague” (Van Gogh, 1888; Bertamini, Palumbo, Gheorghes & Galatsidas, 2015; Ramanchandran, 2000).
In gauging such a quote one cannot help but think of certain paintings like *The Starry Night* (1889) or *A Wheatfield with Cypresses* (1889) and their distinct brushstroke curvature. The intentional guiding of a viewer’s attention however need not be limited solely to one technique, but rather will vary with artist and genre. Baroque era painters like Rembrandt and Vermeer for instance instead harnessed color contrast and texture variations to orient and guide viewer attention toward desired portions of an image, often this being the eye-region of a portrait (DiPaola, Riebe & Enns, 2010; Healey, Tateosian, Enns & Remple, 2004).

Talented artists thus hold at their disposal a wide repertoire of techniques for manipulating aesthetic preference, the rules of perception, and the human visual system. Given such talents and abilities one cannot help but think that much of what a skilful artist can accomplish, is in sync with the knowledge of a neuroscientist (Zeki & Nash, 1999; Cavanagh, 2005). Indeed throughout much of psychology’s history what has emerged from the laboratory couples well with the creations of an artist. In light of this, the thesis now turns to a modern day problem concerning the computer science subfield information visualization, where an issue exists for which the techniques of an artist may be especially fruitful, namely, how does one create an aesthetically pleasing and highly functional data depiction.

1.3 Information Visualization & Aesthetics

Information visualization is a subfield within computer science that seeks to display spatial-numerical datasets to human users through an image that can be easily explored, communicated, analyzed and efficiently summarized (Card, Mackinlay, & Shneiderman. 1999; Healy, Tateosian, Enns & Remple, 2004; Lau & Moere, 2007). One of the standard ways to accomplish this has become *glyph-visualizations*, in which attributes of the original dataset are mapped onto and displayed through visual properties such as shape, color, size, orientation and...
texture (Borgo et al., 2013). Given that these visual properties can combine in a variety of ways, glyphs allow for a great deal of freedom and potential in effectively depicting complex multivariate datasets and underlying variable associations. For instance consider a weather map glyph as reported by Ware & Plumlee (2013) in which the relative size of arrowheads correspond to wind speed, color to temperature, wind direction to orientation, and number of arrowheads to pressure, figure 2.

Although numerous highly detailed and easily understandable glyph visualizations can be found, creating a visualization that is both functional and aesthetically pleasing often poses a problem (Chen, 2005; Kosara, 2007; Filonik & Baur, 2009). As datasets become increasingly complex, multivariate, and available in large quantities through technological innovations, finding methods of effective visualization is critical (Chen, 2005; Tateosian, Healey & Enns, 2007). Artists on the other hand frequently excel in such scenarios, often depicting complex scenes, nuance details, and highlighting the intricate features of an image. The techniques of an artist hence might offer an avenue of visualization that is both aesthetically pleasing and highly effective (Tateosian, Healey & Enns, 2007).

1.4 The Present Study

The primary goal of the present thesis is to harness the expertise, knowledge and painterly techniques of artists in order to create effective data visualizations. This goal in part guided by the work of Tateosian and colleagues (2007) who identified various visual attributes and features associated with different impressionist era paintings. These features included paint thickness, degree of brushstroke curvature, overall stroke shape and color variegation. By assessing these different painterly attributes, three unique impressionist styles were identified, interpretational complexity (IC), indication and detail (ID) and visual complexity (VC) and
computer algorithms then created such to render a given image into that impressionist style (Tateosian, Healey & Enns, 2007). A brief discussion of each style follows, with example paintings of each style presented in figure 3 and examples of each visualization in figure 4.

The first impressionist visualization style identified by Tateosian and colleagues (2007) is titled interpretational complexity, bearing similarity to artworks such as Water Lillies, Evening Effect (1897-1899) by Claude Monet. For this impressionist style, an undercoating of paint defines overall image shape and homogenous areas of detail. On top of this layer individual details are added with brushstrokes of varying thickness, ink and wetness. The image hence consists of two distinct paint layers, the first serves as a general base and provides a relatively lower level of detail while the second layer comprises individual brushstrokes applied to depict more nuanced or elaborate portions of the image. By creating two such distinct layers, certain portions of the image will be highly homogenous and less visually alluring compared to areas in which additional details have been added through individual strokes, thus through this layering procedure, contrast and variation signal to the viewer areas of importance (Ramachandran, 2000).

The painterly techniques associated with the style indication and detail can be found in artworks like Irises (1889) by Vincent Van Gogh. The techniques pivotal to this style differ from those of interpretational complexity in that instead of creating contrast, they seek an overall sense of unity and cohesion. Highly variable or important portions of the image are depicted with clear and dense brush strokes whereas homogenous areas are drawn with fainter sparse strokes. Connecting these different portions are transitional strokes which have gradual and intermediate levels of density and detail. Hence these connecting strokes allow for a smoothness and transitory segue for different portions of the image. Simple or less evident strokes help omit
extraneous details, while the gradually more detailed strokes communicate to the viewer portions of the image that require the most attention and interpretation (Wooding, 2002; Holman, Vertegaal, Sohn & Cheng, 2004).

Lastly techniques associated with the style visual complexity may be found in paintings like *The Starry Sky* (1889) and *Road with Cypress and Star* (1890) both by Van Gogh. Unique to this style, great variation may occur within the actual brushstroke itself. Some strokes for instance may begin straight and with relatively little paint, and as they continue onward the stroke curvature increases and paint thickens. Each stroke hence may be unique and provide for a special footprint within the image. Highly detailed portions of the image quickly become evident to the viewer through vast brushstroke variation, hence creating a complexity not otherwise found in homogenous or less important areas (Berylne, 1971). Viewers thus are alerted to which areas may require greater interpretation, and made aware of potential relationships that exist between variables as evident through increasing brushstroke variety.

These three impressionist visualization styles provide the current thesis a means of adopting and applying the painterly techniques of skilful artists. In testing these techniques, a series of weather maps were obtained from the International Panel of Climate Change, with each map containing a large quantity of data, including mean temperature, cloud cover, wind speed, frost frequency, precipitation, radiation and vapour pressure. Hence these multivariate maps allowed for a practical image set from which to build a foundational set of studies. Each weather map was then rendered into one of three impressionist styles and the industry standard glyph *(figure 4)* and two experiments were conducted to test two key features of an effective data visualization, data recognisability and the ability to communicate data trends.
The first experiment tested visualization recognisability. Participants were asked to rate a series of visualizations presented one at a time on a computer screen, and in random order, on their perceived complexity and arousal. These ratings were included such to encourage participants to view and judge each image, rather than letting them passively progress from image to image. The particular categories themselves, were in part chosen based off the earlier work of Berylne (1973) who emphasized the importance of complexity and arousal in understanding aesthetic experience, and in part given that recent studies continue to fruitfully apply both categories in research concerning aesthetics (Eskine, Kacinik & Prinz, 2012; Sun, Yamasaki, & Aizawa, 2014).

After a set number of trials participants completed a surprise new-old recognition test. During this test, participants were presented one at a time either visualizations they had previously seen, or, visualizations that were new, and had to be labelled accordingly. After this test participants completed 3 additional sets of rating trials and 3 subsequent memory tests. Through this procedure we were able to test if impressionist visualizations were comparable to, or superior, to glyphs on data recognition.

The second experiment tested how effective each visualization style was in communicating data trends to the viewer. To do so a different set of participants completed a set of trials in which all four visualization styles were presented equally and in random order. After each visualization was briefly displayed, participants were asked to identify what percentage of the previous visualization was blue, where the color blue could be representative of any particular weather condition (e.g. mean temperature). As this task requires individuals to provide information concerning a trend existing within the data, this task was titled a trend identification task. By having participants complete this task, an assessment and comparison could hence be
made between impressionist styles and glyphs in their ability to communicate data trends to the viewer.

Incidental eye tracking done during both experiments provides insight whether into impressionist styles fostered greater viewer interest and inspection of an image relative to glyphs. In considering this claim, the variables fixation count, fixation duration and pupil dilation were all considered. Given that studies have associated image liking with greater visual exploration and pupil dilation (Janisse, 1973; Maughan, Gutnikov & Stevens, 2007; Wang, 2011) it was expected that impressionist visualizations modeled after talented artists, would similarly elicit greater visual exploration and pupil dilation.

Taken individually the two experiments each test a critical feature associated with successful data visualizations, recognisability and trend identification. Taken together and along with obtained eye-tracking results, they test the broader hypothesis that by harnessing the expertise and knowledge of artists we may create aesthetically pleasing and highly functional data visualizations.
Chapter 2: Experiment 1 – Recognition

2.1 Participants

A total of 30 University of British Columbia undergraduates (15 male and 15 female, mean age = 20.2 $SD = 2.01$) completed the experiment in exchange for course credit. Participants were recruited through a university human subject pool in which study sign up was voluntary and of individual choosing. All participants provided informed consent prior to participating, had normal or corrected-to-normal vision and were naive as to the purpose of the experiment. On study completion all participants were debriefed about the experiment purpose.

2.2 Stimuli and Apparatus

Stimuli were provided by the International Panel of Climate Change and consisted of 32 weather maps from the years 1961 to 1990. Each map depicted a wide variety of weather conditions, including monthly mean temperature, precipitation, wind speed, cloud cover, frost frequency, vapour pressure and radiation. Four different continents, North America, South America, Africa and Asia were each depicted with 8 maps respectively. Each of the 32 maps were rendered into the industry standard glyph and the three impressionist styles, interpretational complexity, indication and detail, and visual complexity (Tateosian, Healey & Enns, 2007), thus resulting in a total image set of 128. An example of each visualization style may be found in figure 4. All stimuli and study instructions were presented on a LCD monitor set to a refresh rate of 60Hz with a screen resolution of 1600x1200. Participant’s eye movements and pupils throughout the experiment were recorded by an SR Eyelink 1000 set to a sampling rate of 1500Hz.

2.3 Procedure
Participants were welcomed to the laboratory, seated in a comfortable chair and asked to rest their heads on a chinrest 70cm from a computer monitor. After being seated, instructions were provided both on screen and verbally, and a nine-point eye tracker calibration was conducted. An experimenter was present in the room for the entire testing session, to ensure that the eye tracker remained calibrated and to answer questions should they arise. Participants then completed one practise trial in which they were shown an example weather map and asked to provide a rating of perceived complexity, a series of rating trials then followed.

During the rating trials participants viewed weather maps with a resolution of 750x750 on a computer screen for five seconds per trial. After this time the weather map was removed and replaced by a single question pertaining to perceived image complexity or arousal. There were a total of eight complexity themed questions, in which participants provided a rating on how complex, intricate, complicated, elaborate, simple, plain, easy or basic they perceived the image to be. Similarly there were eight arousal themed questions asking participants how arousing, stimulating, awakening, provocative, boring, stale, sleepy or dull the previous image was. Both complexity and arousal themed questions contained four positively worded items and four negatively worded items. Participants responded to each question by selecting a number from 1 to 6 on an adjacent keyboard, with 1 being “very little” and 6 being “very much”. Participants had as much time as desired to provide a response, following which a fixation cross appeared on screen for 500ms and then the next trial would begin.

After 16 rating trials, participants completed a surprise new-old recognition test. Participants were informed that they would see 32 images one at a time and would specify if the present images on screen was previously seen in the prior rating phase. After being informed that half of images in this test were indeed in the previous rating phase and that half were not,
participants began the task. Participants labelled an image as previously seen by pressing “Y”, or as not seen by pressing “N”. After completion three more rating blocks coupled with three additional memory blocks followed. Each rating block randomly and without replacement depicted maps exclusively of one continent, North America, South America, Africa or Asia with the paired memory block having those same 16 maps and 16 unseen foils. After every 10th rating trial a calibration check was done to ensure accurate eye tracking.

2.4 Statistical Analysis

In total participants completed 64 trials in which they rated weather maps on perceived complexity and arousal. Negatively worded items for both categories were recoded such to calculate a single mean. Glyph mean complexity was 3.95 ($SD = 1.32$), interpretational complexity 3.67 ($SD = 1.21$), indication and detail 4.12 ($SD = 1.18$) and visual complexity 3.88 ($SD = 1.31$). Glyph mean arousal was 3.21 ($SD = 1.54$), interpretational complexity 3.21 ($SD = 1.21$), indication and detail 3.42 ($SD = 1.21$) and visual complexity 3.45 ($SD = 1.45$). A summary of the mean complexity and arousal ratings for each presentation style may be found in figure 5.

An overall mean accuracy for the 128 memory trials was computed, glyph visualizations had a mean accuracy of 86.1% ($SD = 34.6$), interpretational complexity 83.2% ($SD = 37.4$), indication and detail 81.9% ($SD = 38.5$) and visual complexity 84.8% ($SD = 35.9$). A mean accuracy of 50% would correspond to chance level guessing. Participant hits and false alarms were calculated for each art style. Hits compromised trials in which participants correctly identified an image as previously seen, and false alarms trials in which participants identified an image as previously seen when in fact it had not been previously presented. Following this a $d'$-prime value was calculated for each participant and visualization style according to the formula

$$d' = z(pH) - z(pFA)$$

where $pH$ is the probability of a hit and $pFA$ is the probably of a false alarm.
A higher value of $d'$ hence represents better recognition performance, expressed in standard deviation units such that a $d'$ of 1 means the signal is estimated to be 1 standard deviation unit stronger than noise. When the proportion of hits or false alarms was on the ceiling or floor, the associated values of 1.0 and 0 were replaced with .001 and .99 respectively (MacMillian & Creelman, 1991).

Incidental eye-tracking occurred during the rating phase of the experiment. For each art style the following measures were computed: fixation count which represents the sum total of fixations made, fixation duration which is the time in milliseconds spent looking at a portion of an image prior to the next following fixation, and pupil dilation which measures how much an individual’s eyes dilated following image exposure.

### 2.5 Results

Participants completed 64 trials in which they rated each images of each visualization style on perceived complexity and arousal. Following a repeated measures analysis of variance (ANOVA) a main effect of style was found for complexity ($F(3,87) = 3.17, p < .05$) but not arousal ratings ($F(3,87) = 1.10, p > .05$). Follow up Tukey’s HSD revealed that the impressionist style indication and detail was rated as being more complex than interpretational complexity at the .05 level.

Across four blocks participant’s completed a total of 128 new-old recognition trials. Hits and false alarms were calculated and a mean value of $d'$ was computed for each visualization style. Mean $d'$ values for each participant and visualization style were then analyzed in a repeated measures ANOVA. A significant main effect of style was found ($F(3,87) = 3.85, p < .05$), figure 6. Further follow-up tests using the Fisher’s LSD procedure indicated that the pairing of glyph and visual complexity resulted in significantly larger $d'$ value than the pairing of
interpretational complexity and indication and detail \((F(1,29) = 10.20, p < .05)\). No differences however were found between glyph and visual complexity \((F(1,29) = 1.18, p > .05)\), nor interpretational complexity and indication and detail \((F(1,29) = .16, p > .05)\).

Participant’s eye movements were recorded during the rating phase of the experiment. For each visualization style a mean sum total of fixations, mean fixation duration and mean pupil dilation were calculated. Impressionist visualizations relative to glyphs were associated with more fixations \((F(3,29) = 14.2, p < .001)\), shorter fixation durations \((F(3,29) = 5.57, p < .05)\) and greater pupil dilation \((F(3,29) = 93.52, p < .001)\), figure 7.

2.6 Discussion

One key feature of a successful visualization is whether or not the user can recognize the image and the associated data depicted. The primary goal of the this experiment was to compare recognition performance of glyph visualizations relative to three impressionist styles, interpretational complexity, indication and detail and visual complexity. To do so participants rated a series of images of each visualization style on their perceived complexity and arousal, after which participants completed an old-new recognition test. A mean hit and false alarm value were computed for each visualization style and an associated \(d’\) calculated. Visual complexity visualizations were found to be comparable to glyphs, and together this pairing was superior to interpretational complexity and indication and detail. One might argue however that correctly identifying an impressionist visualization as either previously seen or not was a more challenging task, given that the impressionist images were likely more similar to one another than they were to glyphs. Regardless however, visual complexity visualizations were highly memorable such to be on par with the current industry standard glyphs. Furthermore impressionist visualizations elicited greater viewer interest and visual exploration as implicated by a higher fixation count,
shorter fixation duration and greater pupil dilation. Given that past studies have linked aesthetic preference to more fixations and greater pupil dilation, our eye-tracking results seem to imply that indeed participants had a preference for impressionist visualizations relative to glyphs (Janisse, 1973; Maughan, Gutnikov & Stevens, 2007; Wang, 2011)

Lastly we found differences in the subjective ratings participant’s provided for each visualization style. In particular the impressionist style indication and detail was rated as more complex than interpretational complexity. Speculatively, future studies of data visualization might consider if an ideal mix of complexity may be found for optimal memory performance.
Chapter 3: Experiment 2 – Trend Identification

3.1 Participants

A total of 31 University of British Columbia undergraduates (16 male and 15 female, $M_{age} = 20.5$, $SD = 2.71$) completed the experiment in exchange for course credit. All participants provided informed consent prior to participating, had normal or corrected-to-normal vision and were naive as to the purpose of the experiment. One participant was excluded from eye-tracking analysis due to equipment malfunction.

3.2 Stimuli and Apparatus.

The base images, display equipment, and recording devices were identical to Experiment 1. Images now however were further grouped based on categories of blue within the image: 0-20%, 21-40%, 41-60% and 61-80%. For each map blue was representative of a single weather condition, for instance mean temperature. Each of the four percentage blue categories were displayed an equal number of times for each continent and style and were presented in a random order.

3.3 Procedure

The experiment followed a similar procedure to the experiment 1, except instead of being asked to provide a subjective rating of complexity or arousal after seeing a visualization, participants were asked what proportion was blue. Each visualization appeared on screen for five seconds and was then replaced by the question “What percentage of the previous map was blue?” with the following four accompanied response options “1. 0-20%”, “2. 21-40%”, “3. 41-60%” and “4. 61-80%”. Each answer was correct an equal number of times relative to the other options and participants selected their choice via keyboard button press. Lastly and different from
experiment 1, all four continents along with their associated visualizations now appeared in an entirely random order.

3.4 Statistical Analysis & Results

Participants completed 64 trials in which they had to specify the percentage of blue present within a briefly displayed visualization. As each response option was correct an equal number of times relative to the other options, participants strictly by guessing could achieve an accuracy of 25%. Through this task we assessed if impressionist painterly techniques were beneficial for trend identification relative to glyphs. Mean accuracy for glyphs was 57.5% ($SD = 12.9$), interpretational complexity 61.9% ($SD = 15.4$), indication and detail 61.3% ($SD = 17.4$) and visual complexity 66.1% ($SD = 13.9$), figure 8.

Using accuracy as the dependent measure, a repeated measure ANOVA revealed a significant main effect of visualization style ($F(3,90) = 3.96, p < .05$), with follow up Tukey’s HSD revealing that visual complexity was superior to glyphs at the .05 level. Replicating experiment 1 impressionist visualizations also elicited more fixations ($F(3,29) = 11.1, p < .001$) and greater pupil dilation ($F(3,29) = 142.6, p < .001$) relative to glyphs. Different however from experiment 1 however no effect of fixation duration was found ($F(29,3) = 1.44, p > .05$).

3.5 Discussion

A successful data visualization is able to clearly show patterns and trends that otherwise are difficult to detect or otherwise may have gone unnoticed. The primary goal of the second experiment was to compare impressionist visualizations relative to glyphs in their ability to communicate and make salient certain data trends. To do so participants completed 64 trials in which after brief exposure to a data visualization, they were required to identify what percentage of that visualization was blue. The color blue for a given visualization was depictive of a single
weather condition, for instance mean temperature, wind speed or radiation. Following analysis
the impressionist style visual complexity was found to be superior for this task relative to glyphs.
Hence it would seem that the painterly techniques associated with visual complexity, as
exemplified in the paintings *The Starry Sky* (1889) and *Road with Cypress and Star* (1890) by
Van Gogh, are particularly well suited for identifying data trends. Arguably then, by
manipulating within stroke variation, intricate features of the visualizations were made
particularly salient and expressive (Ramanandran, 2000).

Similar to experiment 1, impressionist visualizations relative to glyphs elicited more
fixations and pupil dilation. Different from experiment 1 however there was no effect of fixation
duration. Given the nature of the task, a more consistent fixation duration across participants
might tentatively have been expected, as an active searching strategy was more likely to be
adopted by participants. Alternatively the task itself may have been more anxiety provoking
given its active nature and as such may have influenced fixation duration.
Chapter 4: Conclusion

Throughout the history of psychology numerous scientists have sought to identify features and attributes associated with beauty, aesthetics and general perception. Intriguingly these findings have often linked back and corroborated with what talented artists had already been doing in their studios. Certain paintings for instance have been reported to depict the golden ratio (Livio, 2008), while others seem to clearly exemplify Gestalt principles of perception. Further studies have found that individuals exhibit a preference for horizontal and vertical lines relative to oblique lines, and smooth contours over sharp contours (Latto, Brian & Kelly, 2000; Latto 2004; Johnson, Muday & Schirillo, 2010; Latto & Russell-Duff, 2002; Bar & Neeta, 2006), with numerous artists long since seemingly modeling their artworks in sync with these preferences (Latto & Russell-Duff, 2002; Bertamini, Palumbo, Gheorghes & Galatsidas, 2015).

The present thesis sought to harness this rich reserve of knowledge by modelling the painterly techniques of impressionist era painters and applying them toward a modern practical problem within the subfield of computer science, information visualization. As data become increasingly complex, multivariate and accessible in large volumes through technological innovation, scientists are often left uncertain of how to create aesthetic visualizations that effectively communicate and summarize those datasets. To address this problem we rendered a series of weather maps into four distinct visualization styles, one being the industry standard glyph and the other three modelled after the painterly techniques of impressionist era painters. By creating these impressionist visualizations artist painterly techniques were empirically tested on two key features of successful data visualization, data recognisability and the ability to communicate data trends. Two experiments followed in assessing this potential.
The first experiment tested whether or not impressionist visualizations were more recognizable than glyphs. To test whether or not this was the case participants rated visualizations one at a time on their perceived complexity and arousal, and then completed a surprise new-old recognition test. Values of $d'$ showed that visual complexity visualizations were found to be comparable to those of glyphs and that the pairing of visual complexity and glyph were superior to interpretational complexity, and indication and detail. Hence while no distinct advantage of impressionism was found, visual complexity images were highly memorable and on par with glyphs. It may be speculated however that correctly identifying an impressionist image may have been more difficult than correctly identifying a glyph image, as the impressionist visualizations were arguably more similar to one another than glyphs. Hence one might reason that achieving high memory performance was more difficult for impressionist visualizations.

Experiment 2 tested a different key attribute of a successful visualization, the ability to communicate to the viewer trends and patterns within the data. In testing whether impressionist visualizations were beneficial for this task, participants completed trials in which visualizations of the four styles were briefly presented and then replaced by a question asking what percentage of the previous map was blue, with four accompanying response options. Results showed that the impressionist style visual complexity had higher accuracy on this task relative to glyphs, thus providing evidence that the painterly techniques associated with visual complexity, specifically within brushstroke variation, fostered trend identification. As evident in the findings of experiment 1 and experiment 2, there seems to be a unique effect of the painterly techniques associated with visual complexity. By highlighting portions of the image through within stroke
variation, something is being accomplished that otherwise is not through the painterly techniques of interpretational complexity and indication and detail.

Eye tracking results of both experiments yielded similar findings, impressionist visualizations elicited more fixations and greater pupil dilation. One exception however was that while experiment 1 demonstrated impressionist visualizations to have shorter fixation durations, experiment 2 did not replicate this finding. This might be accounted for given nature of experiment two requiring a more active searching strategy, or perhaps being more anxiety provoking. Collectively however these eye-tracking results suggest that impressionist visualizations aroused greater viewer interest, and were potentially more aesthetically pleasing relative to glyphs (Janisse, 1973; Maughan, Gutnikov & Stevens, 2007; Wang, 2011).

In broadening our findings to the current literature on aesthetics, we cannot help but reflect back on the comparison of artists being akin to neuroscientists (Zeki & Nash, 1999; Cavanagh, 2005). By carefully exaggerating, distorting and omitting extraneous details, a skilful artist navigates our attention, communicates image contents, and produces an aesthetically pleasing image that often is profoundly different from what might be captured by a photograph. Indeed, should one seek novel ideas for research, they might do well to witness an artist applying certain painterly techniques, and then questioning how this influences the human visual system. The resulting research may not only helps identify the unique knowledge artists have, but may provide guidance in solving highly practical problems as those one might encounter in information visualization.

4.1 Limitations and Future Directions

Participants in both experiments were exposed to visualizations for a relatively brief period of five seconds. Whether or not the current findings of our experiments still hold when
this time-frame is altered remains an intriguing and potentially limiting question. Perhaps by presenting visualizations for shorter or longer period of time, different results might be obtained. For instance, if all visualizations were to remain on screen for a substantially longer period of time, would glyph visualizations eventually become as successful as impressionist visualizations in depicting data trends? Potentially so, though one might also expect this not to be the case given that aesthetically pleasing images might promote longer inspection and greater intrigue.

Given less time constraints, or perhaps even free viewing, there may or may not be advantages for impressionist visualizations relative to glyphs. One speculation though, provided free viewing, those visualizations that are most liked, might be most thoroughly inspected, or for a longer period of time, hence bolstering the effectiveness of the data visualization.

Although the current thesis was concerned with identifying how impressionist painterly techniques may be incorporated into data visualization, we may question the extent to which our stimulus set of weather maps actually depict and sensibly agree with what an impressionist would actually paint. Data visualizations are of course substantially different from the pastoral landscapes or portraits impressionists were more commonly known for depicting. An image set more in sync with art genre might then yield somewhat different results. Vincent Van Gogh for instance once write that “Painters understand nature and love her and teach us to see her” (1888), perhaps implying that his painterly techniques are more suited for this particular medium. For instance whether photographs of nature relative to photographs of other contents rendered into impressionist styles yield different memory results would be a speculation worth pursuing.

Another question concerns what aspects of impressionism might be most responsible for our obtained results. Descriptions of impressionists frequently note their unique approach to curvature and brushstroke variation (Reutersvärd, 1952; Berezhnoy, Postma & Van Den Herik,
2005) and meticulous study of visual properties like luminance and color (Roberts, 2013; Schapiro, 1997). Impressionist Georges Seurat for instance was known to copy paragraphs from texts concerning color theory and color contrast, and in particular from the text *et de l’assortiment des objets colorés* by Michel Eugène Chevreul (Kirby et al., 2003). Alternatively commentary and insight into colours can be found by reading letters Van Gogh had written to his brother Theo "When the complementary colors are produced in equal strength, that is to say in the same degree of vividness and brightness, their juxtaposition will intensify them each to such a violent intensity that the human eye can hardly bear the sight of it" (1885). The relative strengths of these visual properties and their application in achieving memorability remains an exciting question.

Although this thesis was chiefly concerned with the painterly techniques of impressionism, studying other art genres would likely provide further insight. Baroque painters for instance preferred the use of textural variation to highlight and draw attention to particular portions of a painting (DiPaola, Riebe & Enns, 2010). Whether or not this differential style of guiding viewer attention is comparable to impressionism on tasks of memorability and trend identification would be an enticing comparison to make. Perhaps more broadly the effects of any particular art style are most accentuated when there is a match between painterly techniques and image content.
Figure 1

Image (a) depicts the gestalt principle of multistability in which depending on the viewer’s attention either a face or vase may be perceived. Image (b) depicts the principle of similarity in which items that share a common feature, in this case color of circle, are perceived as belonging together. Below these two images are artworks that display the same principles respectively, (c) *Apparition of Face and Fruit Dish on a Beach* (1938) by painter Salvador Dali and (d) a woodcut print titled *Sky and Water I* by Escher (1938).
Figure 2

A glyph visualization as reported by Ware & Plumlee (2013) in which the relative size of arrowheads correspond to wind speed, color to temperature, wind direction to orientation, and number of arrowheads to pressure.
Figure 3

The three impressionist techniques characteristic of each visualization style, interpretational complexity, indication and detail, and visual complexity, are respectively displayed in the three paintings below, (a) Water Lillies, Evening Effect (1897-1899) by Claude Monet, (b) Irises (1889) and (c) The Starry Night (1889) both by Vincent Van Gogh.
Figure 4

An example of a single weather map rendered into a (a) glyph visualization and the three impressionist styles (b) interpretational complexity, (c) indication and detail, (d) visual complexity.
Figure 5

In experiment 1 participants rated weather maps of glyph and impressionist visualizations. Mean rating for perceived arousal and complexity are depicted for each visualization style.
Figure 6

In experiment 1 participants completed a new-old recognition test. Memory performance measured in $d'$ is presented for each visualization style. IC = interpretational complexity, ID = indication and detail, VC = visual complexity.
Figure 7

Participants’ eye movements were recorded during the rating phase of experiment 1. Mean sum total of fixations, mean fixation duration and mean pupil dilation are presented for all visualization styles. IC = interpretational complexity, ID = indication and detail, VC = visual complexity.
Figure 8

In experiment 2 participants were shown visualizations and had to identify percentage blue.

Mean accuracy for all visualization styles are presented.
References


Dali, S. (1938). Apparition of face and fruit dish on a beach [Painting].


Web.


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