Art, Affect and Color: Creating Engaging Expressive Scientific Visualization

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ABSTRACT

As the complexity of scientific data and the needs to communicate the science have grown, the requirements for visualization design and use have become more sophisticated. We increasingly need more effective ways of communicating the science across multiple audiences, including non-experts in the field. The challenges of enriching the representation have moved from the more naive ideas of making it "aesthetically attractive" to more profound constructs of visual language: how to enhance nuances in the data, and how to support more expressive visualizations that elicit different cognitive and communicative affect to tell the science story. In this paper, we describe how artistic color techniques drawn from paintings can be operationally applied to produce more evocative and informative scientific visualization. We illustrate how the color use in a painting can reveal structure and information by evoking different cognitive and affective responses. Scientists, visualization designers, and artists use visual language to define and evoke experiential response (affect); and expressive: to convey feeling and evoke experiential response (affect); and directive: to command and/or prevent response and action [17]. These perspectives reflect the communicative intents of the creator, and understanding these perspectives are fundamental to leveraging expertise from those disciplines to enhance the clarity and the affective impact of communication. Scientists have languages all their own, typically based on mathematical constructs and honed representation that is simultaneously rich and comprehensible, and ensuring that the affective message - the experiential and emotional "tone" of the data story - is appropriately conveyed.

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These kinds of design, communication, and articulation skills are often foreign to scientists who simply want to "see the data" in the most detailed and expeditious way possible.

Our work bridges this gap by melding artistic and affective color theory and applying them to the needs of scientists to build knowledge, techniques, and tools accessible to the individual scientist creating visualizations. In this paper, we present color palettes extracted from paintings to demonstrate how principles from the artistic language of color design combine with affective color theory to create more evocative and informative scientific visualizations.

Our work provides scientists with (1) a theoretical overview of artistic and affective color theory; (2) color palettes that they can easily apply to their own work; (3) a guide for choosing the most appropriate palette based on their data structure and tasks; and (4) an explanation of how to apply a prefabricated palette to a data set using ColorMoves, a free online Scientific Visualization tool, (5) instructions for extracting an original palette from a piece of art.

1 INTRODUCTION

The capability of the scientific community to present a clear, engaging, and accessible vehicle for understanding the principles upon which decisions will be made is critical to enhancing scientific insight and increasingly, to communicating the science to multiple audiences including non-experts in the field. These challenges relate to both information and affect: distilling the data into a visual representation that is simultaneously rich and comprehensible, and ensuring that the affective message - the experiential and emotional "tone" of the data story - is appropriately conveyed.

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2 COMMUNICATIVE INTENT: DATA TO LANGUAGE

Visualization researchers and scientists think of color as a tool for exposing data whereas artists think of a visual language with its own semantic and expressive structures and scope. These are fundamentally different perspectives. The Oxford English Dictionary defines language as a “method of human communication, either spoken or written, consisting of the use of elements in a structured and conventional way; the phraseology and vocabulary of a particular profession, domain or group.” We use language in three ways: informative: to communicate content; expressive: to convey feeling and evoke experiential response (affect); and directive: to command and/or prevent response and action [17]. These perspectives reflect the communicative intents of the creator, and understanding how artists, visualization designers, and scientists use visual language to define and construct those communicative intents is crucial to leveraging expertise from those disciplines to enhance the clarity and the affective impact of visualization. Scientists have languages all their own, typically based on mathematical constructs and honed representation that is simultaneously rich and comprehensible, and ensuring that the affective message - the experiential and emotional "tone" of the data story - is appropriately conveyed.

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We build on this work by examining the intersections of affect color and cultural, personal, experiential and use a range of tools to connect and impact their audiences on an affective and reflective level. All use similar elements of visual vocabulary toward related and complementary goals, but with different communicative intent and manipulations of emphasis, organization and technique.

To date, scientific visualization research and design has focused on the purely informative aspects of visual language, focusing on the perceptual and cognitive effectiveness of graphical representations of data to facilitate reasoning [23]. The objective of effective visualization design is to represent data with visual features for accurate cognitive interpretation. Affective visualization, on the other hand, uses visual features to evoke a mood, feeling, or impression [27].

The affective context in which data representations are communicated and interpreted is often accidental or at best a secondary consideration, discussed as a topic of aesthetic design [18, 47]. While the importance of aesthetics and good design is acknowledged as fundamental to engagement, interest, and engagement, [18, 26, 46] this discourse has only touched in passing on the larger design space of affect. We argue that affect forms an important dimension of many visualizations. Its use in visualization applications is an emerging field of study in our traditionally “objective” discipline, as researchers identify its importance in data storytelling [7, 42], engagement and persuasion [28], cognitive enhancement [3, 10], and contextual framing [13].

Affective communication poses a particular challenge for the science community trained in precise accuracy but untrained in telling a story, emphasizing importance or eliciting engagement. This evocation of connection, feeling, reflection, or emotion is central to the creation of engaging experience: a communicative intent increasingly articulated by scientists who want non-experts to understand not only their data but also the import and implications of their findings.

Understanding color, and how artists explore both the descriptive and the expressive richness of it, can increase both the clarity and the affective impact of a visualization. In this paper we present a means for the scientists to tap the affective potential of color while maintaining and enhancing the accuracy of their science.

3 RELATED WORK

There is a clearly demonstrated desire within the scientific community to use color to both increase the informative as well as affective properties of their visualizations. In order to facilitate engagement but guidance as well as an easy-to-implement system has been elusive. Numerous systems and tools for creating effective colormaps such as ColorBrewer, ColorCAT, have been developed, many tied to artistic color theory [5, 11, 21, 34, 49, 50, 56] and validated by the perceptual community.

The scientific visualization community has largely relied on perceptual sciences to construct color solutions [56]. However, increasingly, the scientific community understands the need to communicate more affectively in addition to effectively, by partnering with artists and designers [32, 48, 51, 52, 54]. Research centers such as NASA, NOAA, JPL and NSERC have collaborated with artists on scientific visualizations [8, 30].

Extracting palettes from art is not unexplored territory as documented in recent work by Phan, Lynch and others [19, 24, 31, 38, 39]. We build on this work by examining the intersections of affect color theory and artistic color contrast theory and practice to build a methodology drawing from this combination.

While there is much debate about the characteristics of a good colormap [4, 5, 22, 25, 35–37, 50, 56], well documented by Zhou in 2016 and supported in subsequent work, [6, 12, 21, 31] that is not the focus of this paper. In contrast to this work, our contribution rests on the combined application of artistic expertise and affect theory to engage and motivate audiences both within and beyond the scientific community. We present a means for scientists to create affective visualization [43, 44, 48, 53], visualization designed to evoke a mood, feeling, or impression. We address the need for awareness of color impacts and how to use color characteristics for engagement.

3.1 Affect Theory

Affect is a concept used in psychology to describe experiential response: feeling, impression, mood, or emotion. It is typically classified by the well-known PAD model of affect [33] that plots them in a dimensional space defined by pleasure (valence) and arousal axes. Valence covers hedonic range, from positive (happiness, pleasure, love) to negative (pain, anger, sadness, fear). Arousal reflects intensity from calm (unaroused, relaxed, sleepy, etc.) to excited (high arousal, stimulated, nervous, alert, etc.). Typical emotions such as surprise, disgust or compassion can be placed in this 2D space (see Figure 2); extensive emotion research has defined many more nuanced affects (such as affection or boredom) in this model as well.

While designers and artists understand the more complex properties of palettes (organized groups of colors), there has been relatively little research specifically on the affect of palettes and visualization. Recently, Bartram et al.’s study of affective color sets in visualization [27] showed that simple 5-color combinations selected for categorical mappings differed significantly by affect. Figure 2 illustrates the most common colors selected for palettes for the four poles of the affect axes, where size represents frequency of use.

While the warm cooler palette of Van Gogh’s Irises is not a naturally associative set of hues for science domains, it is useful as a complementary palette if one has multiple visualizations to compare. Combustion data shown here (J. Chen, Sandia) comes alive in Van Gogh’s palette. Compare it with the cool warm example in Figure 11.
Figure 4: Secondary color palettes such as the one used here by Cezanne, evoke a sense of melancholy, a common affect of muted more nuanced hues. While the Manet in Figure 1 is also built using a muted palette, the reliance on primary hues enables it to maintain a positive affect.

These colors were selected from a set of 41 possible, and by definition their importance in the palette was normalized: that is, in categorical mapping, no palette color had more inherent weight or importance than any other. Even in this limited color space, there are clear patterns in the different affect groups. This study also looked at other palettes mapped to different affects located in the 2D affect space and found they combined colors from the 4 polar color groups, reinforcing the correspondence between the validated PAD space and color space. However, this work looked only at limited palettes and categorical mapping. We turn to artistic color theory to enrich the affective understanding of more complex palettes and visualization applications.

3.2 Artistic Theory: The Language of Color

In 1960, Johannes Itten published *Art of Color: The Subjective Experience and Objective Rationale of Color*, which examines symbolism of color, the emotional subjective feeling associated with hues, and the contrasting objective color principles [15]. The multifaceted approach to understanding color aligns directly with our approach that addresses the full capacity of color and its impact on scientific visualization. Color contrast theory was developed and refined over centuries but it was Itten, followed by Albers, who formalized its place as the foundation of painting practice and the basis upon which artists construct images.

Color contrast theory is the means used to systematically structure a painting, creating thematic relationships, visual categories and hierarchies within the work, allowing the viewer to visually determine the relative importance of various aspects of the work. We will discuss this in Section 5. First, we need to define the terms and concepts underpinning artistic color contrast theory.

3.2.1 Basic Definitions

Artistic color contrast theory further characterizes color contrast into seven types [16]. Below is a brief summary and other relevant color terminology discussed here.

1. Value Contrast: the range between white and black, light over dark.

2. Saturation Contrast: the purity of the color; the amount of gray mixed in with the pure hue; fully saturated colors dominate lower saturation levels.

3. Complimentary Contrast: opposites on the color wheel; red, green; blue, orange; and yellow, purple.

4. Analogous contrast: hues adjacent to one another on the color wheel, provides contrast with lower levels of color interaction; yellow, green, blue and yellow, orange, red are the standards.

5. Cool/Warm Contrast: blues and greens are cool; reds to yellow are warm colors.

6. Contrast of Extension: the portion of area verses the visual intensity of a color. For example, to be in balance one would need only a small amount of red to balance a larger area of gray.

7. Simultaneity: vibration caused by abutting saturated hues. This is a critical principal to consider in scientific visualization as the rainbow colormap is comprised of fully saturated hues and thus produces significant visual vibration.

8. Color Triad: three colors equally spaced the color wheel: red, blue and yellow (primaries); orange, green and purple (secondaries).

Figure 5: Goya's *The Third of May*, left, leaves no doubt that the subject matter is serious. The hues extracted from the painting, center align clearly with the hue set identified as serious in the affect study.

Figure 6: Jan van Eyck’s *The Arnolfini Wedding Portrait*, left and color contrast types, right: B. value contrast C. saturation contrast D. complimentary and cool warm contrast E. analogous contrast, muted hue value contrast, saturation contrast.

Figure 6 diagrams itemized color contrast types, as demonstrated in Jan van Eyck’s *The Arnolfini Wedding Portrait*, painted in 1434.

3.3 Perceptual Science

Perceptual scientists consider color using the CIE model of three color axes or channels: blue-yellow, red-green and black-white (achromatic, related to lightness or more correctly luminance) [20, 50]. The properties of color common to visualization design from perceptual principles (see [45, 50] for a comprehensive discussion) are hue, saturation (or chroma, the colorfulness or distance from gray), and lightness, the value from black to white. Vision scientists define contrast as the difference in luminance or color that makes an
work with the interactive properties of color and the perceptual com-
This methodology blends knowledge discussed above from artistic
study of affective color in visualization [27] that are the foundation
artistic palettes. See below for more detailed explanation.
object (or its representation in an image or display) distinguishable from other objects and the background.
We note the different terminology used by artists and perception scientists while reinforcing the commonality of the larger constructs the terms identify. The concept of language use is more powerful, however, it is the structure of thought and a primary means of communication and shared understanding.
Perceptual color theory is outside the scope of this paper, as we focus on affect and artistic color theory, the impact of which has been studied less frequently in reference to scientific visualization.
4 Linking Affect, Artistic Color Theory and Scientific Tasks
This methodology blends knowledge discussed above from artistic and affective color theory to enable scientists to create visualizations that are accurate, informative, and affectively engaging. The palettes and recommendations, all available on SciVisColor.org, enable scientists to easily explore their data, identify its features, and communicate its informative and expressive qualities.
Affective customized palette choices will assist scientists with engaging other scientists, funding agents, and the public. The environmental science community widely recognizes the need to frame issues like climate change using humanities-inflected modes of communication and interpretation like storytelling [14]. Hulme prioritizes the need for more engaging affective communication over further factual documentation to bring about actionable change. Given the fundamental role of visualization in understanding climate science, incorporating methods from the arts and social sciences such as artistic color theory and affect theory have the potential for impacting society.
As Figures 4, 5 and 9 demonstrate, artists use relationships between color and the affects created by these relationships to construct the expressive meaning of a work of art. While designers and artists work with the interactive properties of color and the perceptual community has contributed to the accuracy of color encoding data, there has been relatively little research specifically on the affect of visualization palettes. As mentioned, Figure 2 diagrams Bartram et. al.’s study of affective color in visualization [27] that are the foundation of the affect categories used in our methodology.
These colors were selected from a set of 41 possible hues. Even in this limited color space, there are clear patterns in the different affect groups. This study also looked at other palettes mapped to different affects located in the 2D affect space and found combined colors from the four polar color groups, reinforcing the correspondence between the validated PAD space and color space.
While this work looked only at limited palettes and categorical mapping, our extracted color palettes extend the range, interaction impact, and affect to help scientists determine how they can use color and relationships between colors to best tell the informative and affective story, taking into account their data structure and the tasks they need to perform.
As an introductory example to our methodology, consider Figure 1, which shows Edouard Manet’s 1874 painting Monet in his Studio Boat, a visualization of magnetic reconnection data in a palette extracted from the painting: the affect theory calm set; the extracted palette and an asteroid impact simulation [29] using the analogous palette.
The affect of the visualization using the Manet palette mimics the affect of the painting. In the painting, we see how the use of an analogous, cool palette aligns affectively with emotions of calmness and pleasure. Though a mostly analogous palette, the use of muted ochre and orange, (warm tones that contrast with the blues of the painting and are associated affectively with excitement) on the triangular shape of the flags draws our focus to Monet and indicates that he is important to the piece’s informational and affective terrain.
While we are considering the Manet palette notice Figure 7 comparing the magnetic reconnection data in six different colormaps. The top row shows the data rendered in the standard rainbow; the cool warm narrowed to the center range of the data; the rainbow in a format used by scientists seeking more detail and the bottom row a standard linear colormap moving through multiple analogous warm hues, in the narrowed data range; and a customized distribution of the Manet palette, adjusted in ColorMoves. The rainbow reveals the issues with applying a standard colormap without adjustment. The cool warm, even in the narrowed range lacks both detail and affect. The triple rainbow does not lack impact, nor does it provide information or affect. On the lower row, a standard analogous cool hue range colormaps, in the narrowed data range provides the calm and positive affect. The blue orange divergent is shown in comparison to the cool warm map above, documents why wider hue ranges and or higher saturations are not always an advantage on noisy data. The final example employs color scales from the Manet palette, in a customized structure aligning with the data, conducive to exploration and providing a means for feature identification. Customizing the structure was accomplished via ColorMoves at SciVisColor.org [40].
Exploration is facilitated by the muted values of the cool, analogous extracted palette that align with the cluster of hues identified as calm by affect theory. The calming affect combined with the analogous low contrast between the hues proves particularly useful when applied to noisy data sets like the magnetic reconnection data because its muted colors are distinguishable but not a strong contrast causing simultaneity vibration.
While of limited use in visualization due to the low contrast ranges, Goya’s The 3rd of May shown in Figure 5, has been included because it aligns with the affect hue set identified as serious, where browns have been associated with sad and stale ratings. Figure 9 demonstrates the opposite side of the spectrum, a wide fully saturated hue range and a playful affect.
5 Aligning the Palette
We have spoken a good deal about affect, color contrast theory and, artistic palettes. In this section, we demonstrate how these align to impact the informative quality given specific tasks common in visualization. With Figure 8, we provide a chart that maps out the relationship between artistic color contrast theory, affect, data distribution, and visualization tasks, [35]. We present a few general strategies for employing color’s inherent properties on different
types of data and for different tasks. It is important to note that this is not a comprehensive guide, but instead a starting point for further research into understanding alignments between color theory, affect, and scientific data structure and needs.

One of the reasons that color selection for scientific visualization is such a complex process stems from the interactive impacts of adjacent hue, extensively studied in depth by Albers [1]. In scientific visualization, hues and their surrounding contrasts are determined by the distribution of the data rather than by the orchestration of the artist. Artistic knowledge and principals such as low saturation and analogous palettes can help alleviate unintended and often cacophonous interaction. The type and impact of color interaction is primarily determined by the type and level of contrast which is why in the diagram shown in Figure 8, it is listed in a separate category.

5. Contrast types: hue, value, saturation, complementary, cool warm, analogous, triads

Figure 8 contains a table with suggestions for selecting the best suited palette characteristics. While these are subjective, we have provided examples of each throughout the paper in order to demonstrate the results.

On one axis are the artists’ palettes, and the other, the categories of tasks, data type, affects, color contrast types, and color structures. The grid is populated with recommendations aligning the specific palettes to the categories.

Generally scientists know their task and overall data distribution, this is the starting point. Figure 8 outlines characteristics and usages in each artist’s column. Select the one that most closely aligns with the data and scientific goals.

For example, if a scientist is working with a hierarchical data set, a good choice would be the color palette extracted from Picasso’s Seated Woman, a painting shown in Figure 10, that employs varying degrees of saturation, a property closely associated with attention and thus able to direct a viewer’s attention in sequence by applying the highest saturation to the area of importance and then descending in saturation and attention level simultaneously.

In Picasso’s Seated Woman, your attention is first drawn to the red and black triangles, hues highest in saturation and value contrast, respectively. The yellows, bright green, and orange are the next to draw attention, followed distantly by the muted blue and yellow background, making it clear that the information in these areas is secondary.

6 APPLYING THE PALETTE

6.1 Directing Attention via Color Hierarchy

Colors have a range of strengths which align with the level of attention they attract. Thus the strength of a color scale needs to be aligned with the areas of importance with in the data. Bolder hues are the first to attract attention. In general the higher the saturation the stronger the hue and thus one aligns the most saturated color from the set with the data of highest importance. For example, in Figure 3 the most important data is assigned to the red color scale and the second most important, to the purple color scale. Both are strong, bold colors but reds attract our attention first.

Once you have selected a palette that aligns with your goals, the next task is to order and assign the specific color scales and discrete hues to align with the importance of the ranges of your data.

6.2 Workflow for Colormap Construction

After you have selected your palette, follow the steps below to apply the extracted palette to your data set using colorMoves, SciVis-color.org/home/colormoves, where detailed instructions on the entire process are available. Figure 11 provides a diagram of the process.
7 Extracting a Palette

As a practical matter, scientists generally do not have the time to explore color palettes within paintings in order to extract palettes for the purpose of creating specific affective custom colormaps. However, here we take a moment to diagram the underlying principles of how paintings are constructed, how one can extract palettes, and use them to build visual in order to expose the reasoning behind the palette construction. The processes are outlined using The Arnolfini Wedding Portrait Figure 6, as an example.

1. Identify the dominant colors in the painting.
   By this we mean, which hues do you see first, second? Which cover the largest areas within the painting? Next notice their characteristics. Do they span from light to dark? Saturated to unsaturated? Do they contain a wide or narrow hue range? The answers to these questions direct your color scale choices. In the The Arnolfini Wedding Portrait the dominant hues are red and green.

2. Determine the information hierarchies.
   What are the most important variables in the data? You will be using the most dominant color scale for this variable. When deciding on hierarchy of the hues, in general the most saturated hues are the most dominant, with warm hues being more dominant than cool hues of similar saturation. One note of caution, emphContrast of Extension will be a factor if the important data covers the largest percentage of the area within the visualization. Be aware that using a fully saturated red over large areas will dominate attention to such a degree that other areas are minimized. To balance this, select a color scale of reduced intensity. Notice van Eyck’s uses the green ranges on top of the red, saving the potency of the red for equally important data that covers a smaller area. Neutral color scales are applied to contextual areas.

3. Identify the supporting hues and contrast types.
   In the van Eyck, the analogous relationship of the blue green and gold (E) as well as the lightness of the facial tones against
the dark background (B and C) make up the secondary color relationships. For a visualization, these provide options for discrete colors representing related variables.

4. Consider the contextual hues, sometimes considered background. Surrounding neutral tones impact the hierarchy in subtle ways, often related to the complimentary color relationships or value distributions. For example, a cool blue-gray background, such as the default in ParaView, will lessen the dominance of a saturated blue but increase the impact of a warm hue such as red or orange. Thus it is worth considering the contrast relationships of hues that provide context for the main themes within the painting; lower levels of contrast in background areas can reveal significant amounts of information. Note the detailed elements within the van Eyck, rendered in brown tones, that provide quite a bit of detailed information without distracting from the focus of the saturated areas shown in Figure 6 (B, F and G).

8 Discussion
There are several caveats and words of caution related to the use of this means of palette development for scientific visualization. Primary considerations are discussed here.

8.1 Painting Selection
The specific paintings that were selected for this paper align with the categories of the affect theory palettes. Exploring palettes outside of the Western art tradition would provide a wider range of palettes, but is beyond the scope of this work.

Color usage varies widely by culture, tradition, available pigments, and location as well as time period. Most of paintings we examined come from the Western Artistic Tradition in the later part of the nineteenth and early twentieth centuries. We have drawn from this movement and time period because of the intense exploration of color and color affect, but also because these are the most contemporary works (thus widest pigment range) that fall outside of copyright protection, sidestepping complications and expense.

Contemporary palettes have evolved, often with a specific focus on the interaction of the color itself over the subject matter. For this reason, we have included one contemporary painting, the usage of which was generously granted by artist Brush Marsh, known for his ability to construct complex natural scenes from very narrow palettes. *Seagrapes*, an oil painting, demonstrates the ability of a narrow palette to convey complex information. The narrow saturation range of this palette, which includes a wide green hue span is in contrast to the other works included here, demonstrating the evolution in color in painting, and its growth through color field painting into current artistic practices [9]. Take a close look at the detail Marsh is able to extract from the restricted palette. This is an interesting principal to bear in mind when selecting source material. By narrowing the overall saturation and hue ranges Marsh has quietly increased the perceived contrast within the work [1, 50].

8.2 Viewpoints: Art, Design, and Perception
Basic color theory deals with interactions of color and color balance but does not take into account affect nor the specific needs of the scientific community.

Design verse art is a murky division that goes back as far as the fields have been identified. Here we speak broadly and cautiously - in general, the intention of an artist is to present images and or experiences to which the viewer brings their own experience. The combination provides a unique experience for each member of the audience. Design focuses on employing visual elements to convey a specific message.

While the designers’ palettes are every bit as refined and nuanced as those from the artistic community, the investigation into affect of complex color palettes is an inherent focal area for painters.

8.3 Domain Convention
Domain convention plays an important role in color selection for scientific visualization. While we have considered individual domains in previous work [41], and the topic is certainly pertinent to this discussion, the range of domains and their conventions will span several papers in order to scratch the surface.

9 Limitations
Our approach brings several issues and potential drawbacks to the fore of the design discussion. While we have developed palettes by mining numerous paintings, our methods do not define nor identify appropriate paintings a priori, so the selection of a source artwork by a scientist may not guarantee the desired perceptual and affective
A key limitation of our work to date concerns validation. While the expressive scope of palettes using palettes applied to data such as engagement, we intend to carry out more targeted studies testing the community.

9.1 Validation

A key limitation of our work to date concerns validation. While the visualizations in this paper are actively used and are validated through iterative practice with scientists, we have not yet evaluated interpretative features through controlled studies. That said, the work stands on the centuries of expertise developed within the artistic community.

As we move into more nuanced expressions of affect and engagement, we intend to carry out more targeted studies testing the expressive scope of palettes using palettes applied to data such as those compared in Figure 12. More generally, we have only touched the surface of the potential in mining the wealth of artistic knowledge and artifacts for visualization design methods. Beyond color, representational forms include line, shape and texture; structure includes transparency [2], layering, and depth. What can we learn from other data representation abstractions beyond scalar color? Future work may include: research of affective palettes for specific domains; recommendations for scientists in selecting palettes with the desired affect and appropriate structure; assessing the specific areas of value through iterative interviews with scientists included here and from other disciplines; and looking into contributions beyond the visual arts. While we have only begun to explore this intersection of art and data, our work seeks to extend the visualization discourse from the strictly informational to the more richly expressive.

10 Conclusion and Future Work

Our work highlights the impact of bridging existing affective color theory and artistic color theory in a format easily transferred to scientific data.

Affective palettes and color selections shown here are not all-inclusive or definitive. While they are representative of basic artistic and affect theories, they do not account for the full complexity that emerges from theorizations of relationships and interactions between colors. Future work includes expanding the color set used in the affect study to include a wider range of hues and relationships drawn form artistic color theory, such as the secondary color triads demonstrated in Figure 3, the painting’s secondary colors (green, orange and purple) form the base of the Irises palette, producing a powerful affective combination.

The purpose of our work is to provide scientists with an easy, readily available means of creating engaging visualizations able to speak to our humanity as well as our intellect. To that end, all of the components needed to implement our system are available on line, free for all to use at SciVisColor.org.

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References
