

Recreating Van Gogh's original colors on museum displays

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Abstract

The colors of Van Gogh's landscape painting *Field with Irises near Arles* have changed considerably. To digitally reconstruct its original colors, we use an unprecedented broad scientific analysis and experimental art technological approach, by physically reconstructing oil paints of all pigments used by Van Gogh. We closely match the original paints, and for the first time determine all the optical properties involved. The investigation led to a digital image representing the original colors as good as possible.

We found that for the digital color reconstruction it is important to take into account that museum lighting is often relatively dark in order to better preserve paintings. Since this affects the best way of representing the reconstructed colors on the display, we adapted the digital reconstructed image. We also corrected for the technical specifications of the electronic display on which the reconstructions will be displayed in the museum.

Based on the reconstruction we conclude that the original colors in the painting used to be much brighter, and agreed much better with Van Gogh's own description of the color composition of this painting. We show that unlike the current colors of the painting, the reconstructed colors are consistent with the color theories on which Van Gogh based his work.

Introduction

Nowadays, paintings by the artist Vincent van Gogh speak to a wide audience. The striking and brilliant colors of his art works from the Southern France period create an expressive style that fascinates numerous admirers. However, many of the colors used in these works have dramatically changed over time, mainly due to light exposure [1][2]. Some color changes can be attributed to yellowing of varnish [3][4], while others are caused by degradation of pigments [1][2][5][6][7][8].

Since these paintings cannot be physically restored to their original colors, only reconstructions offer the possibility of recreating their appearance as intended by the artist. Over the past few years, digital reconstructions of several paintings by Van Gogh and other Post-Impressionist artists have been published. Most of this work has been conducted by affiliates of the Rochester Institute of Technology, including investigation of Van Gogh's series of *The Bedroom* [6][9], *The Starry Night* [10] and George Seurat's *A Sunday on La Grande Jatte* [11]. These pioneering investigations formed the foundation for later studies on Van Gogh's paintings of *Undergrowth with Two Figures* [12], *Irises* [13], *Roses* [13] and *Self portrait* [14]. A number of other studies have appeared that aim to account for the color change caused by the varnish [15][16].

To date, the aforementioned studies have been limited by utilizing reflectance data from 50 or fewer selected spots on the paintings, and by digitally refreshing only one or a couple of pigments. A summarized below, we improved on these aspects in

recent work. But the previous investigations were in need for other improvements as well. None of the previous reconstructions considered the lighting conditions the digital reconstruction will be viewed, and what color characteristics are specific for the electronic display used for displaying the reconstructions. The current paper proposes an improved treatment on both aspects.



Figure 1. Visualization of current colors in *Field with Irises near Arles*. The colors in this image are calculated from the spectral reflectances as measured by hyperspectral imaging, and corrected for varnish.

Summary of previous results

To examine the original colors of the painting *Field with Irises near Arles* (Figure 1), created by Van Gogh in May 1888, we conducted an analysis that is unprecedented in the comprehensiveness of techniques applied, abundance of technical data and depth of scientific and art historical analysis. We utilized hyperspectral reflectance data from 1.7 million spots on the painting, and digitally replaced all the pigments. In this way we accounted for both varnish discoloration and pigment degradation. The analysis included various imaging techniques applied on the full painting, as well as analytical, spectroscopic and microscopic techniques used on paint samples taken from the painting [17][18][19][20]. We prepared several reconstruction paints according to information in historical sources on raw materials and production processes and used the ones most resembling Van Gogh's paints. We analyzed all data with optical models, colorimetric analysis and massive computation, and complemented this approach with art historical expert judgment.

After determining the spatially resolved concentrations of all pigments, we determined the values of the optical scattering and

absorption parameters for each pigment in its state immediately after application. This allowed us to calculate the spectral reflectance of the fresh pigments for every spot covered by the hyperspectral measurement. Using common sRGB color space, we used the calculated spectral reflectance maps to calculate tristimulus values X, Y, Z and digital color parameters R, G, B.



Figure 2 Visualization of original colors in the painting. The colors are shown to have been much brighter originally. The irises showed a wide variety of purples rather than the current blue, and many whitish dots in the current painting were originally pink. Similar to Figure 1, the visualization is intended to be shown on a generic display at 1000 lux ambient light conditions.

In just three cases, the available data was found to be insufficient for this approach to be fully successful. This entailed areas of the painting depicting the sky, whitish dots and irises. In these instances, discussions within the broad multidisciplinary project team allowed us to make informed decisions.

Figures 1 and 2 show the current painting after correcting for yellowed varnish, and its digital reconstruction. While green colors now dominate the field, the reconstruction separates a greenish-yellow area from the bright yellow field behind it. Half of the field had indeed just been mowed before the painting was created, as Van Gogh mentioned in a letter (number 612) [21]. In the same letter the artist described the color composition in the painting as "that sea of yellow flowers with a line of purple irises". The reconstructed colors match this description well, unlike the current blueish colors of the irises. Our results show that the original colors of the irises ranged from bluish to reddish purple [22].

Accurate representation on museum display

In the current paper we investigate how the image representing the digital reconstruction is best used for actual use on an electronic display in museums. For this, we need to correct for both the influence of ambient lighting on color perception and on the variation between different electronic displays in representing colors.

When viewing the digital reconstruction on an electronic display, the colors appear differently when viewed under different lighting conditions. In the conservation studio of the Van Gogh Museum we compared the digital representation of the aged painting, based on multispectral reflectance data, with the physical aged painting. This showed that the colors of the digital

representation looked more yellowish than the corresponding colors in the painting [17]. This was caused by the spectrum of the ambient light in the conservation studio, having a correlated color temperature of 5198 K instead of the 6500 K that is assumed when calculating the digital representation with common sRGB color space. We conclude that it is important to account for the spectrum of the local museum lighting when calculating digital representations.

The illuminance level of the ambient lighting also strongly influences the optimum color representation. Surveys of practice across a range of major museums show that museum lighting is often below 200 lux, in order to reduce the risk of light-induced damage to artifacts on exhibit [23]. The standard sRGB model to calculate the R, G and B color parameters of digital representations gives optimal color accuracy at a much higher ambient illuminance level of approximately 1000 lux [24]. Therefore, using this standard digital color representation would result in a digital reconstruction of the painting that would be much brighter than the colors of the physical painting observed under the same museum lighting conditions. This would also affect the perceived colorfulness of the digital reconstruction.

We also need to consider another critical aspect when creating the digital reconstruction. Its colors vary with the type of electronic display used to represent them. Therefore, the technical specifications of the electronic display should be taken into account when creating an accurate digital color representation. For the iPad Air 2 display, it has been reported that white images become "slightly too blue" [25][26]. On the other hand, dark images are shown with a blue cast, possibly due to the antireflective coating on the display [24][26]. For example, images with red values $R < 50$, and with $G=B=0$ appear clearly purple rather than dark red. For an accurate representation of the calculated original colors of Van Gogh's painting on an iPad Air2 display, we need to correct for these color shifts. On this type of display especially the blue primary deviates from the characteristics implied by the standard sRGB model [27].

We recently developed the MDCIM model (Mobile Display Characterization and Illumination Model) to account for both ambient illuminance level and for the technical specifications of electronic displays [24][28]. For creating the digital representation of *Field with Irises near Arles*, we used this model to account for the technical specifications of the iPad Air2 display. The reddish purple colors of some reconstructed irises would be displayed as bluish purple on an iPad Air2 display, if we would use the common sRGB color space for calculating the digital representation. The MDCIM model will correct for this, and it will also remove the blue cast when displaying dark parts in the reconstruction image.

Figure 3 shows three images of the digital reconstruction of *Field with Irises near Arles*, calculated specifically for the iPad Air2 display. They represent the reconstructed colors of the painting as viewed under ambient illuminance levels of 1000, 600 and 200 lux. Obviously when viewed adjacent to each other under ambient illuminance levels much brighter than 200 lux (as is expected to be the case for the reader of the proceedings in which this article is published), these images appear increasingly dark. But when viewed on an iPad Air2 display and under ambient lighting as specified when calculating the reconstruction images, the digital reconstruction is the closest approximation to the original colors of the painting if it would be viewed under the corresponding museum lighting conditions.

The calculated images are calculated specifically to be viewed on the iPad Air2 display. For example, the color of the more reddish purple irises are calculated to be more reddish than when calculated with the standard sRGB model, in order to compensate for the blue cast imposed by the iPad Air2 display.

Discussion and conclusions

The digital reconstruction of the original colors of *Field with Irises near Arles* that resulted from this investigation has implications on the interpreted color composition of the painting, and also on our understanding of the way in which Van Gogh applied contemporary color theories in this painting and how he was influenced by Japanese woodblock prints which he had collected in Paris. These aspects are discussed in separate sections below.

Color Composition

The reconstructed colors of the painting agree much better with the color composition intended by Van Gogh than the colors of the aged painting. While green colors dominate the field area of the aged painting, in the digital reconstruction the green dominance is restricted mainly to the front part of this area, leaving the more distant field areas predominantly light-yellow. This agrees much better with Van Gogh's description of the color composition in this painting as mentioned in his letters to his brother Theo and to his friend Emile Bernard. In the sketch of the painting that he made for Theo in letter 609 from 12 May 1888, he indicated that the foreground was green and violet, the field yellow, the distant trees "green grey" and the sky blue [21]. In the same simplified way he explained the coloristic effect to Bernard in letter 612 from 22 May 1888 [21]. We already mentioned that unlike the current painting the reconstruction indeed shows green and yellow sections in the field area, and that this can be understood by the fact that part of the field was mowed just before Van Gogh painted the scene.

The color scheme that Van Gogh described in his letters simplified the coloristic effect. We must take into consideration that Emile Bernard at the time was experimenting with evenly colored compositions with clear outlining. In the letters, Van Gogh stressed the simplicity of the color scheme of the painting in terms of Bernard's style, although Van Gogh did not use even color planes to the same extent as Bernard. Vincent and Bernard knew each other from Paris, where at the end of 1887 they worked together while Bernard together with their mutual friend Louis Anquetin developed his new style of simplified forms and even coloring. This new style would later be called Cloisonism. Van Gogh, up to a certain point, experimented with this new style himself, and after his move to Arles the artistic debate between the two painters continued in their letters. With these considerations in mind the reconstructed colors of *Field with Irises near Arles* indeed agree well with the simplified color scheme describes in Van Gogh's letters. The reconstruction brings back the yellow field that is mentioned in those letters as an important aspect of the intended color composition, and that is hardly visible anymore in the aged painting.

Japanese influences

Although Van Gogh did not use the even color planes to the extent Bernard did, *Field with Irises near Arles* is clearly composed of similarly colored planes. The different planes of colour were established early on in the painting process. Van Gogh first used a pencil to draw the main shapes of the landscape onto the white surface of his canvas. He then went on to fill in the



Figure 3. Visualization of the original colors for (a) 1000, (b) 600, (c) 200 lux ambient lighting and specifically for being shown on an iPad Air 2 display, instead of being rendered on a generic display at 1000 lux.

pencil outlines with even planes of colour, using a dark yellow and light yellow in the fields and turquoise in the ditch. A simple colour scheme is also characteristic for the Japanese woodblock prints Vincent favored so much.

Another aspect of this Japanese influence is the use of intense colors. Van Gogh especially liked the intense coloring of contemporary Japanese prints dating from after 1850. The intense light that Van Gogh found in the sunny South of France created the impression of intense colors. This is currently known as the Hunt effect [29], but Van Gogh associated the landscape with its intense colors with his ideas about Japan. These intense colors can hardly be recognized in the current aged state of *Field with Irises near Arles*, but they are strikingly clear in the digital reconstruction.

There are also other "Japanese" aspect of this painting, which was the first painting he made after a three weeks drawing campaign, such as the diagonal composition and the draughtsman's approach in finishing the composition. With a fine brush and intense dark blue paint he overlaid the landscape with a graphic pattern of fine strokes to define the irises, as well as the line of trees and the cityscape in the background. It is reminiscent of the black graphic lines in Japanese woodblock prints that divide the flat color planes.

Contemporary color theories

In his work, Van Gogh made extensive use of the color theory of Charles Blanc. Already in 1884, he had read Blanc's text *Les artistes de mon temps* and *Grammaire des arts du dessin: architecture, sculpture, peinture* [6]. In turn, Blanc's texts were based on the color theory from Eugène Chevreul in his book *De la loi du contraste simultané des couleurs, et de l'assortiment des objets colorés* (1839). It was Chevreul who had formulated the law of simultaneous contrast: two complementary colors heighten one another when juxtaposed. Already in 1885, having read Blanc's description of this law and its application in art by, for example, Delacroix, and having been impressed by paintings by the artist, Van Gogh described himself as being "utterly preoccupied with the laws of color" in the way Delacroix had demonstrated their workings (letter 538 [21]). From then onwards he used this color theory in many of his own works.

According to the color wheel published in Blanc's book, red and green constitute a complementary color pair. The other two complementary color pairs are blue-orange and yellow-purple [30][31]. The digital reconstruction revives the intended color contrasts in *Field with Irises near Arles*. Van Gogh painted the rooftops of the houses more towards orange where they are close to the blue of the sky, and more towards red where they border on the green foliage. According to the color theory of Chevreul, Blanc and Delacroix, both the orange and the red are intensified by the adjacent complementary colors. This intensification is much stronger in the digital reconstruction, because of the much brighter blue and green colors in the reconstructed sky and plant leaves.

Another example of the intended simultaneous contrast that is revealed by the digital reconstruction is formed by the pink dots, representing flowers, at the bottom-left part of the painting. These flowers are surrounded by soft-green colors, and therefore constitute a pair of complementary colors in Blanc's color wheel [30]. In the aged state of the painting, these dots have become white, and the intended color contrast is lost.

The digital reconstruction shows that Van Gogh played subtly with color contrasts. Because of the fading of red lake pigments, the irises in the painting are now quite uniformly blue, and surrounded by a dominantly green field. These colors are not

expected to intensify each other according to the color theory of Chevreul, Blanc and Delacroix. But in the digital reconstruction we recognize the variety of reddish purple to violet hues that Van Gogh used for the irises. Only in the reconstruction are we able to see the intensification of the reddish purple colors at places where the irises are immediately surrounded by green, and the more intense purple that he intended for places where they are surrounded by yellow, as mentioned in letter 612 to Bernard. Van Gogh used many techniques to achieve these color variations in the irises. To this end he not only mixed paints in different proportions, but he also used glaze layers of the red lake pigments eosin and cochineal, applying them in different thicknesses to obtain the desired color effects. We conclude that unlike the current, aged painting, the reconstructed colors fit the color theories on which Van Gogh based his work [22].

The reconstructed colors look much brighter than the current colors of the painting. This is expected for a painter, who wrote to his brother immediately after his move to southern France: "You understand that the countryside of the south can't exactly be painted with the palette of Mauve, say, who belongs in the north and is and always will be the master of grey. But today's palette is definitely colorful - sky blue, pink, orange, vermilion, brilliant yellow, bright green, bright wine red, violet. But by intensifying all the colors one again achieves calm and harmony" (letter 590) [21].

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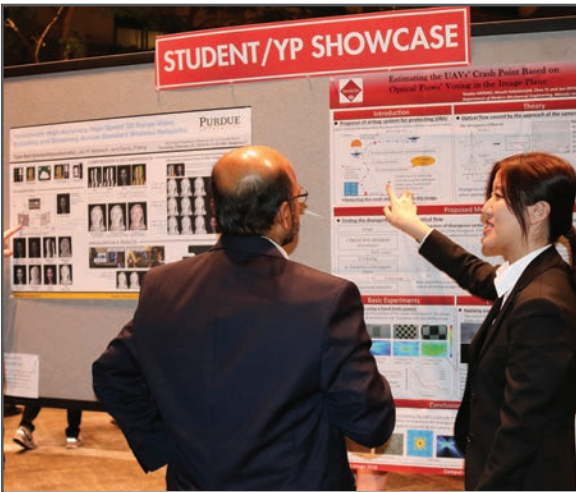
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