https://doi.org/10.2352/EI.2023.35.13.CVAA-209
© 2023, Society for Imaging Science and Technology

Style transfer for improved visualization of underdrawings and ghost paintings:
An application to a work by Vincent van Gogh

Anthony Bourached,[a] George H. Cann,[a] Ryan-Rhys Griffiths,[a]
Jesper Eriksson[a] and David G. Stork[b]

[a]Oxia Palus, London, UK
[b]Independent consultant, Portola Valley, CA 94028 USA

ABSTRACT

We applied computational style transfer, specifically coloration and brush stroke style, to achromatic images of a ghost painting beneath Vincent van Gogh's *Still life with meadow flowers and roses*. Our method is an extension of our previous work in that it used representative artworks by the ghost painting's author to train a Generalized Adversarial Network (GAN) for integrating styles learned from stylistically distinct groups of works. An effective amalgam of these learned styles is then transferred to the target achromatic work.

Keywords: ghost-painting, style transfer, deep neural network, computational art analysis, artificial intelligence, Generalized Adversarial Network (GAN), computer-assisted connoisseurship

1. INTRODUCTION AND BACKGROUND

Many paintings in the Western canon, particularly realist easel paintings from the Renaissance to the present, bear underdrawings and *pentimenti* (from Italian, "to repent")—preliminary versions of the work that the artist altered and refined during the development of the final work. In some cases, artists re-used earlier canvases, for instance obscuring works for which they were not satisfied, in which case entire designs were obscured by a different, visible, design. We call such complete or nearly complete initial works *ghost paintings*. Paintings by Vincent van Gogh, the young Pablo Picasso, among many others, bear such ghost paintings; in one imaging study of 130 paintings by van Gogh, 20 were found to bear ghost paintings.[1] In some cases the ghost paintings are by different authors than the final, visible work.

Of course these hidden works are of interest to art scholars and the general public alike. They help reveal the artistic development of their authors, and may shed light upon works by other authors who saw the works before they were hidden. Moreover, pentimenti prove particularly valuable in authentication studies because copyists and forgers very rarely have access to images of pentimenti and ghost paintings. For example, the pentimenti in ?Leonardo's *Salvator mundi* proved important in authentication efforts for this work because none of the (evident) copies of the work by students and followers of Leonardo showed Christ's blessing hand in the pose in the underdrawing.[2] This evidence suggested the panel painting was autograph.

Imaging and interpreting such hidden works often requires skills rather different from those relevant to traditional connoisseurship.[3] For example, infrared radiography and x-radiography produce images in which the design of the visible artwork and the ghost painting overlap, and it is a visual and cognitive challenge for the analyst to mentally segregate the overlapping images. Furthermore, images of ghost paintings are achromatic, that is, color and related stylistic information is lost.

This, then, is the technical opportunity we explore: how to display a polychrome ghost painting in its likely full style, including most notably its original color.

Sensing methods such as Raman Spectral Imaging can infer the distribution of heavy elements such as Cadmium, Lead, and Chromium throughout a painting, including a ghost painting.[4] These elements are found in many pigments and thus such Raman data can be used to infer likely colors in ghost paintings. However, Raman

Send correspondence to enquiries@oxia-palus.com.

Spectroscopic Imaging requires special equipment that is found in very view museum conservation laboratories, and such imaging is fairly expensive and time-consuming.

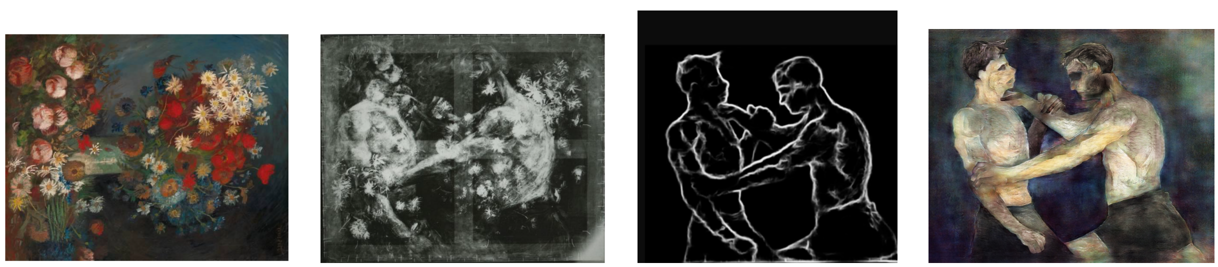
We take a different approach. We view the problem as one based on information and computation, as we explain in the next section.

2. TARGET ARTWORK AND COMPUTATIONAL METHODS

Figure 1 a) shows the painting in question, Vincent van Gogh's *Still life with meadow flowers and roses*. For many years this painting was deemed of uncertain authorship based on its overall style, composition, and other grounds. For stylistic and other reasons scholars concluded that this work, if autograph, was from van Gogh's period in Paris, before he moved to the south of France in 1888 and painted works in a far broader and more saturated palette, including *Irises* and *Sunflowers*. In 2012, after nine years of analysis, a team of researchers elevated the work as autograph van Gogh.[5] Part of the evidence suggesting the work is autograph stems from the underdrawing, shown in Fig. 1 b), and a letter Vincent wrote to his brother Theo in January 1886:[6]

> "This week I painted a large thing with two nude torsos—two wrestlers... and I really like doing that"

No other painting of two wrestlers survives in van Gogh's catalog raisonné—strong evidence that *Still life with meadow flowers and roses* is autograph.

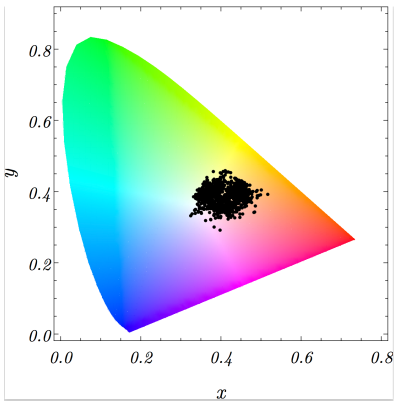


a) b) c) d)

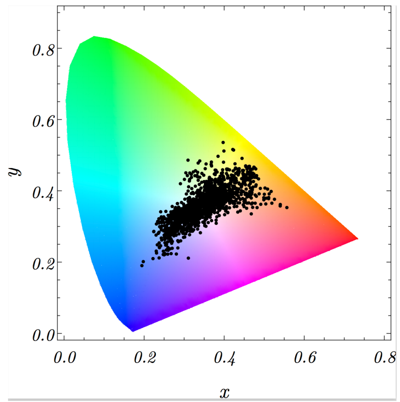
Figure 1. a) Vincent van Gogh's *Still life with meadow flowers and roses* (100×80 cm), oil on canvas (1886), rotated 90° clockwise to match the orientation in b), Kröller-Müller Museum, Otterlo, The Netherlands. b) X-ray revealing the ghost painting of boxers overlapping the design of the visible work, c) deep-net-extracted edge map of the ghost painting, and d) computational style mapped to an edge-detected version of the ghost image in b).

Our computational methods here are based on our prior work, which demonstrated style transfer to pentimenti and ghost paintings behind works by Picasso and Leonardo.[7,8] In broad overview:

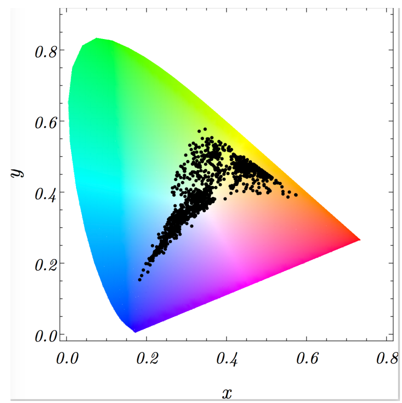
- We applied neural-network-based edge detection to all van Gogh's paintings that depict a person in detail, such as all his self portraits and works such as *La Mousmé*, *Portrait of the Postman Joseph Roulin*, *Young man with a cap*, and *Portrait of a young woman*.
- We semi-semantically labeled the skin portions of these collected images by manually (and roughly) applying a translucent colour over the skin depicted in the images.
- We trained a GAN model to map from the target image to the collected images. In this way the network learned the spatial statistics associated with skin in van Gogh's works.
- We applied edge detection from manually edited version of the x-ray in Fig. 1 b), then labeled the skin, as just described.
- Finally, we mapped the learned style to the target work, to thereby create the image in Fig. 1 d). (The process to this point is similar to our previous work on resolution enhancement.[8])



Netherlands
(1883–86)



Paris
(1886–88)



Arles
(1888–90)

Figure 2. CIE chromaticities of representative paintings from van Gogh's three major artistic and stylistic periods. There are additional stylistic differences between works from these phases, most notably brush strokes and other marks, as well as depicted subjects.

Our current work builds upon the above to include additional steps:

- We selected a set of paintings that represent some of the prominent styles of van Gogh—whether or not they depicted the human figure. We used works in each set of styles to learn separate stylised versions of the ghost image in the corresponding style. This artist passed through three major stylistic periods, each associated with where he was living:
  - First period (1883–86), in the Netherlands, characterized by dark, unsaturated colors with fairly thick, though otherwise traditional, brush strokes.
  - Second period (1886-1888), in Paris, characterized by lighter and more-saturated colors, and depictions of city life.
  - Third period (1888–90), in south of France, characterized by open brush work in thick impasto, and saturated—often complementary—colors.

  We note this step in our processing pipeline is particularly appropriate for van Gogh because of his wide range in styles and content.
- Finally, we computationally merge these styles to produce the final image.

Figure 2 shows the palettes of several representative works in each of the three major periods in van Gogh's career.

3. RESULTS AND ANALYSES

Figure 1 d) shows an intermediate computational result.* Clearly that image is rather crude, though the coloration is plausible and conforms to the contours given in c). This natural and desirable property was not always obtained in our earlier work.

Figure 3 shows the final image. Presumably this improvement is due to our method's learning of separate classes of styles. Notice, too, that the overall lighting on the boxers seems coherent or consistent, as if the source is from below, as one often finds in boxing arenas.

Nevertheless, the renderings of the faces are crude and blocky. The detailed faces are rich in information and any deviation from accurate rendering is particularly conspicuous because of the special nature and sensitivity of face perception among normal human observers.

*A 3D printing of the computed work in Fig. 3 was displayed in the Louvre Museum, Paris, September, 2022.

Figure 3. Final computed version of Boxers, based on segmentation constraints and a GAN deep neural network.

4. CONCLUSIONS AND FUTURE DIRECTIONS

We continue to refine methods for displaying underdrawings and ghost paintings in a style that best conforms to that of the author. In our current work, we found that using a Generalized Adversarial Network to learn separate styles from pre-grouped sets of stylistically unified artworks and then transferring the amalgam of styles to an achromatic underdrawing led to an image that had qualitative properties superior to our earlier work. Specifically, color regions respected the extracted contours, shading and lighting was consistent and superior, and so on. Brush strokes, while surely not of the subtle contours in autograph works nevertheless are respected and conform to the bodies' contours.

Of course despite these improvements, much is yet to be done. Clearly an important step will be to compare results with ground truth. This goals is more subtle than it appears upon first reflection. One can apply our methods above—and future extensions—to edge maps of visible works for which the ground truth color information is of course readily visible. However, an important step in our methods involves extracting contours *from x-ray and infrared reflectograms*—a step that introduces uncertainties.

REFERENCES

[1] S. van Heugten, "Radiographic images of Vincent van Gogh's paintings in the collection of the van Gogh Museum," *Van Gogh Museum Journal* **1995**, pp. 62–85, 1995.

[2] M. Dalivalle, M. Kemp, and R. B. Simon, *Leonardo's* Salvator Mundi *& the collecting of Leonardo in the Stuart courts*, Oxford University Press, Oxford, UK, 2019.

[3] D. Bomford, ed., *Art in the making: Underdrawings in Renaissance paintings*, National Gallery London, London, UK, 2002.

[4] T. J. Benoy, W. A. Edwards, and H. G. M. Edwards, "Evidence of pentimenti for the authentication of paintings: A challenge for analytical science at the interface with art history," in *Raman Spectroscopy in Archaeology and Art History*, P. Vandenabeele and H. Edwards, eds., **2**, ch. 3, pp. 31–45, The Royal Society of Chemistry, 2019.

[5] L. S. van der Loeff, M. Alfeld, T. Meedendorp, J. Dik, E. Hendriks, K. J. Geert Van der Snickt, and M. Chavannes, “Rehabilitation of a flower still life in the kröller-müller Museum and a lost Antwerp painting by Van Gogh,” *Van Gogh Studies* **2012**, pp. 1–25, January 2012.

[6] V. van Gogh, *The complete letters of Vincent van Gogh*, Bulfinch Press, Boston, MA, 2000.

[7] A. Bourached, G. H. Cann, R. Griffiths, and D. G. Stork, “Recovery of underdrawings and ghost-paintings via style transfer by deep convolutional neural networks: A digital tool for art scholars,” in *Computer vision and analysis of art*, D. G. Stork and K. Heumiller, eds., IS&T, 2021.

[8] A. Bourached, G. H. Cann, R. Griffiths, and D. G. Stork, “Resolution enhancement in the recovery of underdrawings via style transfer by generative adversarial deep neural networks,” in *Computer vision and analysis of art*, D. G. Stork and K. Heumiller, eds., IS&T, 2021.