Surface Shape Studies of the Art of Paul Gauguin

Oliver Cossairt*, Xiang Huang*, Nathan Matsuda *, Harriet Stratis†, Mary Broadway†,
Jack Tumblin*, Greg Bearman§, Eric Doehne¶, Aggelos Katsaggelos*, and Marc Walton*
*Northwestern University, Evanston, IL, USA
†Art Institute of Chicago, IL, USA
‡Georgia OKeeffe Museum, Santa Fe, NM, USA
§ANE Image, Pasadena, CA, USA
¶Scripps College, Pasadena, CA, USA
ollie@eecs.northwestern.edu

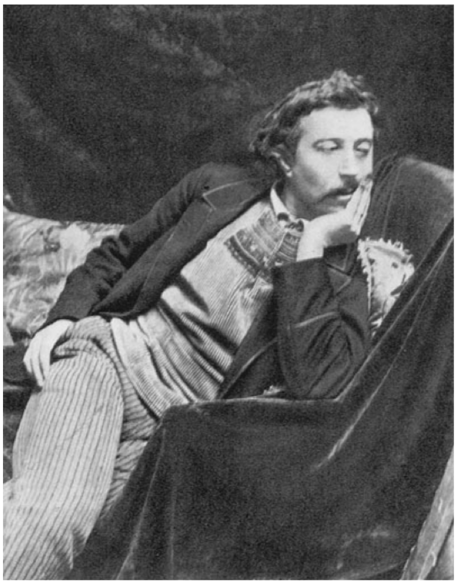


Fig. 1: Paul Gauguin (1848-1903)

Fig. 2: *Day of the God (Mahana no Atua)*, 1894, The Art Institute of Chicago, 1926.198

***Abstract*—Starting in the 1890s the artist Paul Gauguin (1848-1903) created a series of prints and transfer drawings using techniques that are not entirely understood. To better understand the artist's production methods, photometric stereo was used to assess the surface shape of a number of these graphic works that are now in the collection of the Art Institute of Chicago. Photometric stereo uses multiple images of Gauguin's graphic works captured from a fixed camera position, lit from multiple specific angles to create an interactive composite image that reveals textural characteristics. These active images reveal details of sequential media application upon experimental printing matrices that help resolve longstanding art historical questions about the evolution of Gauguin's printing techniques. Our study promotes the use of photometric stereo to capitalize on the increasing popularity of Reflectance Transformation Imaging (RTI) among conservators in the world's leading museums.**

Keywords*—photometric stereo, reflectance transformation imaging, quantitative surface shape measurement, Gauguin, transfer drawings, printmaking techniques.

I. Introduction

One of the greatest challenges in art conservation is to faithfully record the appearance of works of art in order to document their state of preservation [1], to monitor changes to the object over time [2], and to better understand the ways in which materials were used to produce an overall artistic effect [3], [4], [5]. The final appearance of a work of art is the result of how it interacts with light that may be absorbed, reflected and scattered from its surface. While some of these interactions are due to the physical properties of the pigments themselves (e.g. their chemistry and molecular structure), irregularities in the surface shape of both the media and the support play a large role in producing the shadows and reflections that encode the art with dimensionality.

While the molecular characterization of pigments and binding media is a mature and well-defined area of research within cultural heritage science [6], [7], [8], characterizing surface shape has not yet become a routine part of documenting the appearance of works of art. During the last decade, the conservation community has increasingly adopted Reflectance Transformation Imaging (RTI; originally named polynomial texture mapping [9]) as a tool to interactively explore surface relief [10], [11], [12], [13], [14], [15], [16], [17] and features related to the fabrication of objects [18], [19]. RTI methods were originally developed by the computer graphics community [9] as one of several techniques to capture and depict lighting effects for complex materials: fibrous or granular surfaces such as hair, fabric, feathers, pebbles, etc., and to summarize them extremely efficiently for the relatively modest computers of the late 1990s.

The use of RTI has revolutionized the way conservators are able to digitally interact with art. However, the technique

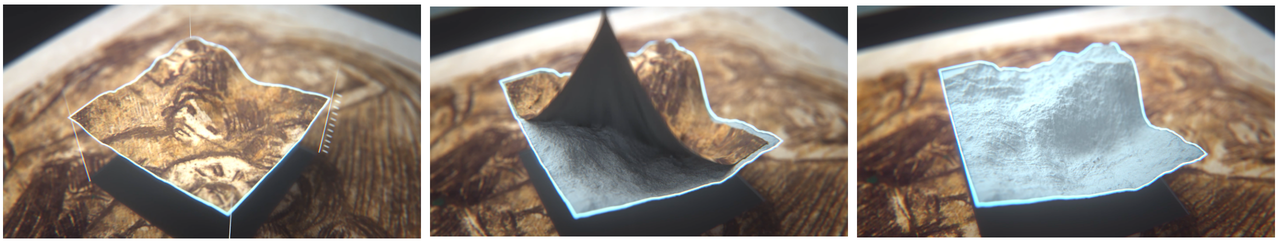


Fig. 3: An illustration of separating surface color from shading information for one of Gauguin's transfer drawings.

is limited by the fact that it is often used in a qualitative manner to visualize the appearance of an artifact under arbitrary lighting. In the studies presented here, a set of photographs taken from known lighting directions were captured to calculate surface shape using the well-known photometric stereo technique [21]. The calculated surface shape was quantified to high precision by placing a calibration target with known 3D shape into the scene. The technique was used to measure the 3D surface shape of the graphic works of Paul Gauguin in the collection of the Art Institute of Chicago (see Fig. 3). From the 3D surface reconstructions of Gauguin's prints and drawings, details necessary to quantitatively assess the manner in which printing inks or oil paint layers sit on the surface of the paper, the order in which they were applied, and the ways in which Gauguin layered his materials in multiple transfers to fashion his end product were revealed.

II. Paul Gauguin

Perhaps one of the best-known Post-Impressionist artist, Paul Gauguin was born in Paris in 1848 and died on the island of HivaOa in the Marquesas in 1903 (see Fig. 1). His brightly colored paintings at first featured Breton subjects, but he is perhaps better known today for his paintings of Tahitians surrounded by the flora and fauna of what Gauguin saw as an exotic, primitive and pure land on the shores of the South Pacific. Using a colorful palette and broad brushstrokes, he brought these lands to life (see Fig. 2).

Less known are the artist's many works on paper, which are the focus of the present study (see Figs. 3 and 5). Gauguin was never formally trained as a draftsman and printmaker thus he was unencumbered by traditional approaches to making graphic art. As a result, he developed novel printmaking and transfer methods to realize his artistic intentions, employing highly experimental materials and fabrication techniques. To this day, art historians and conservators puzzle over these works of art on paper to understand how he formed, layered and transferred images from one medium to another, and, more generally, arrived at his artistic decisions. The work presented here is motivated by two main goals: 1) to assess Gauguin's printmaking and transfer techniques and 2) make quantitative surface shape measurements of Gauguin's prints and transfer drawings.

III. Historical Background

Gauguin only lived to be 55 years old. As a young man in military service he spent several years at sea before becoming a stock broker in Paris. When the stock market crashed in 1882, he took various odd jobs and began to make art in earnest. In the late 1880s he travelled to Brittany, Panama, and Martinique. In 1891 he made his first trip to Tahiti where he intended to escape European civilization and locate a primitive idyll. The landscape, colors, and people he found on the island would remain a consistent subject in his drawings, watercolors, prints, and paintings until his death.

From the start of his career he developed a very experimental style working with a variety of materials. Though he was an avid printmaker and sculptor, he is most well-known for his Post-Impressionist paintings, among them *Day of the God* in the collection of the Art Institute (see Fig. 2).

Gauguin was strongly compelled to bring these images of indigenous cultures back from his travels to share with the Western world. He saw the lifestyle of the Tahitians as pure and untainted by Western advancements and he was determined to disseminate his imagery and his ideas. In late 1893, upon his return to Paris from Tahiti, he prepared an exhibition of 41 paintings and assorted wood sculptures on Tahitian themes as well as three Brittany-related paintings. When they were exhibited at Galeries Durand-Ruel in November of that year, only 3 sold. With them hung on walls and strewn about back at his studio, he used them as visual aids and turned to printmaking as a means to broadly disseminate his visual representations of island life.

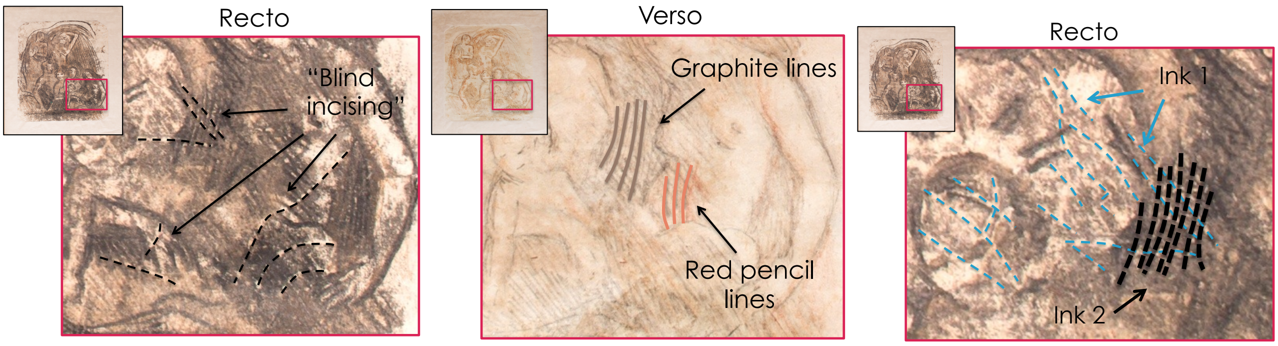
The Art Institute of Chicago is home to over 200 graphic works by Gauguin. The diversity of the collection is representative of the artist's highly experimental artistic style. There are watercolors produced during his first visit to Tahiti, woodblock prints produced in Paris after his return from his first visit to Tahiti, watercolor monotypes, and oil transfer drawings which were produced late in his career. Ironically, Gauguin's art was not much appreciated during his lifetime and his works on paper remained largely unsold.

Fig. 4: *Noa Noa (Fragrant Scent)*, 189495. Woodblock, Metropolitan Museum of Art, 37.97; *Noa Noa*, Art Institute of Chicago, 1940.90, 1948.254, 1948.255, respectively

(a) Recto (Front)

(b) Verso (Back)

Fig. 5: *Nativity*, c. 1902, Art Institute of Chicago, 1922.4317. a) Recto (front). b) Verso (back).



(a) "Blind Incising" (recto)

(b) Colored Lines (verso)

(c) Multiple Inks (recto)

Fig. 6: Visual observations of *Nativity*: a) Broken lines are visible on the front of the transfer drawing that are hypothesized to be caused by "blind incising." b) Two sets of drawn lines are visible on the back of the transfer drawing and were used to apply pressure in a two-step transfer process. c) Two different inks are visible on the front of the transfer drawing, the darker lies atop the lighter, indicating an application sequence of more than one step in the transfer process.

IV. Gauguin's Printmaking Style

Gauguin's various unconventional methods of printing and coloring multiples offered a way for him to produce quantities of relatively affordable and rapidly produced images for the general public.

A. Wood-Block Prints

Gauguin's experimental style is strongly evident in the various impressions of his wood-block prints. Fig. 4 shows an original woodblock and three impressions pulled from that block. Titled *Noa Noa*, it is the first of ten carved boxwood blocks that comprise the series of the same name. Notice that while he was using a technique intended to produce similar multiple impressions of the same artwork, no two of Gauguin's prints are identical. In fact, for many of his prints various media, papers, and transfer techniques were used, resulting in a starkly different impression each time. He often used pigments mixed with resins and wax, watercolor, and printing inks in combination.

B. Transfer Drawings

Now, in contrast to his earlier prints, we consider *Nativity*, which he made near the end of his life in the Marquesas c. 1902. This is a so-called oil transfer drawing on paper. Figure 5 shows the recto (front) and verso (back) of the transfer drawing where the same general layout of the composition on the verso is a mirror image of the recto.

At first glance the transfer drawing looks like it was made in a fairly straight-forward monoprint manner in which a piece of paper is placed onto an inked surface, a drawing is made on the back of the sheet, and when the sheet is lifted from the inked surface, the image is revealed on the front. However, upon closer inspection we can see that the transfer process Gauguin used is quite a bit more complex than this.

V. A Closer look at Gauguin's Nativity

When zooming into the transfer drawing several observations can be made from visual inspection (see Fig. 6). In the area around the mother and child, for example, there are several regions on the recto that contain what appear to be lines where no ink or pigment has been applied (see Fig. 6a). These features have been noted by art historians for decades. Conservators at the Art Institute first concluded that these features were due to "blind incising," which is to say they are indentations in the paper made from previous drawings where ink simply was not transferred. This led to the open question as to whether these features were caused by the underlying surface shape of the paper, a question that can only be answered by measuring the 3D shape of the transfer drawing.

On the back of the transfer drawing, we clearly see marks made from two different pencils; one graphite, the other red (see Fig. 6b). These pencil marks were used to apply pressure to the back of the paper during each step of a two-step transfer process. Two different colors were used so that Gauguin could distinguish between the lines he drew in the first step from the lines he drew in the second step. Additionally, the hardness of the point of each pencil yielded different line widths that Gauguin selectively employed for emphasis or to create depth in his composition.

Coming back to the front of the transfer drawing, visual inspection clearly reveals that two inks were applied to the surface (see Fig. 6c). The first ink is lighter and more brown in tone, and the blind incisions are strongly correlated with this ink application. The second ink is much blacker, and there are many locations where the second ink occludes the blind incisions, giving a clear indication that it was applied over the first ink. This provides a good understanding of the application sequence of the inks in this transfer drawing.

VI. On Richard Field's Theory of Gauguin's Monoprint Techniques

In 1973, art historian Richard Field studied Gauguin's monoprinting techniques and came up with the only working hypothesis that explains the origin of the blind incisions observed in Gauguin's transfer drawings [23]. In Field's explanation, a monoprint is produced by creating a drawing on a piece of paper that has been placed in contact with an inked sheet of paper. Both sheets are then separated, turned over, and stacked in their new orientations. Next a third, blank sheet of paper is placed between the first inked sheet, which has already been used to create the initial monoprint and a fourth, newly inked sheet. By pressing firmly and tracing the initial monoprint, which is face-up on the top of the stack, the artist can effectively create a double-sided monoprint on the third sheet because he has situated it against two inked surfaces. The key to producing blind incisions using this method is that the first inked surface, having already been used in the production of the initial print, has been made devoid of ink where that design was transferred. For that reason, it will yield a skip in the newly transferred design anywhere that new lines cross these areas. Starting with this published method, and assessing its effectiveness using new technology, we wished to discover whether Field's hypothesis could explain the visual imagery observed in transfer drawings like *Nativity*. In particular, we sought an answer as to whether Field's technique could explain the origin of the blind incisions. This is where measuring the surface topography enters as an essential tool in understanding the transfer process that Gauguin used to make his transfer drawings. The three important questions we hoped to answer by measuring the surface shape of his transfer drawing were:

- How were the lines made; how was the media transferred from the inked surface (the matrix) to the paper?
- What is the origin of the blind incisions; are they due to relief structures in the paper, or in the layer of transferred media itself?
- What matrix could produce this effect?

VII. Photometric Stereo

We believed that we could unravel Gauguin's transfer methods by better understanding the surface topography of his transfer drawings. Determining whether an inked line was impressed into the paper to form an embossed image or rather one that stood proud of its surface could provide tell-tale signatures of Gauguin's transfer techniques. This level of detail can be difficult to discern with the naked eye since such features are typically no higher or deeper than the width of a human hair ($\approx 100\mu m$). Additionally, we needed to be able to examine and trace these micron-sized features over the entire transfer drawing and not just small discrete areas. However, visualization of microscopic features over wide areas is not a task suited to most microscopic methods of examination.

To measure the 3D surface of Gauguin's graphic works we used a well-established computer vision technique known as photometric stereo. We captured a sequence of photographs of the artwork from a fixed camera location while changing the direction of the light source. This allowed us to calculate the surface normal at each point by solving a system of linear equations from our set of measurements at each pixel [21]. We do this at each pixel in the image, which gives us an estimate of the 3D shape of the object. We use the Frankot-Chellappa [22] algorithm to produce a least-squares estimate of the 3D surface of the artwork based on the measured surface normals.

Photometric stereo was chosen because it can be implemented fairly easily using components that are readily available to museum conservators. The real benefit of the technique is that it allows the user to recover the topography of an object and separate color from surface shape. Furthermore, the technique can be used to capture 3D surface geometry of large objects (limited only by the magnification of the camera system) with depth resolution on the scale of a pixel as projected onto the scene.

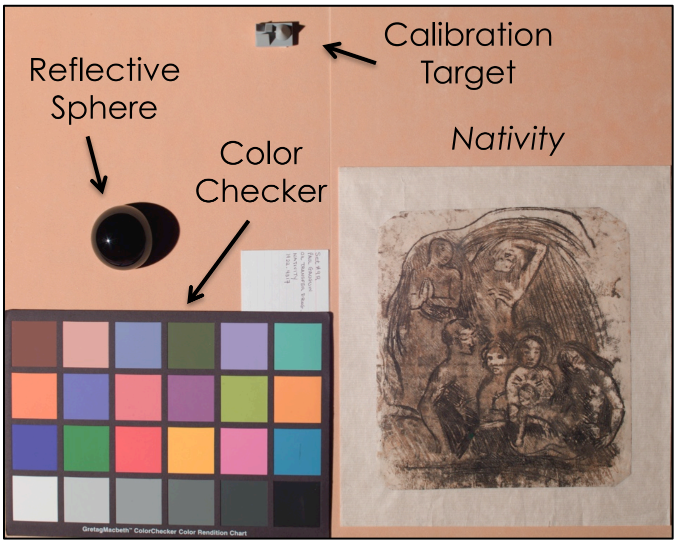


Fig. 7: The setup for capturing photometric stereo of Gauguin's *Nativity*. A color checker for color calibration, a 3D calibration target for 3D surface calibration, a reflective sphere for calibrating light direction, and the work of art.

VIII. Photometric Stereo Experiments on Nativity

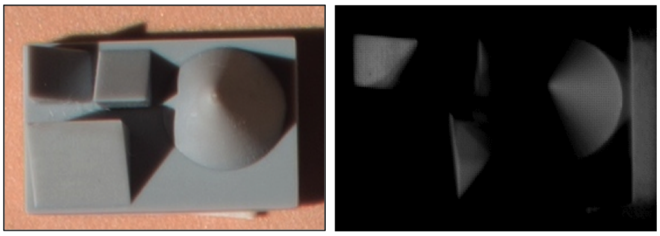
A. Calibration Target

Fig. 7 shows the set-up used to capture photometric stereo of *Nativity*. The transfer drawing is in the lower right of the frame and there is a calibration target at the top, which consists of a cone and a set of three triangles with known 3D shape that we 3D printed ourselves (Fig. 8a). We use this target as ground truth to ensure we are capturing accurate 3D information. After applying photometric stereo, we can peel away the surface color from the 3D surface information. Fig. 8b shows a visualization of the 3D calibration target as though illuminated obliquely from the right. Note that because it is facing the camera, when illuminated from the right, the right side of the cone is bright and the left side is dark.

B. Nativity

We now look at photometric stereo of the transfer drawing itself. Fig. 9a shows a detail at the top of the transfer drawing where a figure with raised arms appears. Again, we use photometric stereo to peel away the surface color from the 3D surface shape. Just like the calibration target, we illuminate the paper's surface with light raking in from the right. We can see clear features at the locations of the dark lines corresponding to the figure's hair. Note that we see the same effect with these lines that we did with the cone: when illuminating from the right, the right sides of the lines are bright, while the left are darker, indicating the lines are protruding from the page.

Origin of lines: The shape of the lines is even more evident when we look at a 3D reconstruction of the surface. Fig. 10 shows a zoom into the area with the lines along with a few frames of a 3D animation. As we peel off the color and shift perspective to look at the 3D surface shape, we see clear evidence of protrusions on the page where ink has been deposited. This is solid evidence of the ink being transferred from a matrix such as that in a monotype transfer process.



(a) Captured photo (b) Shading only

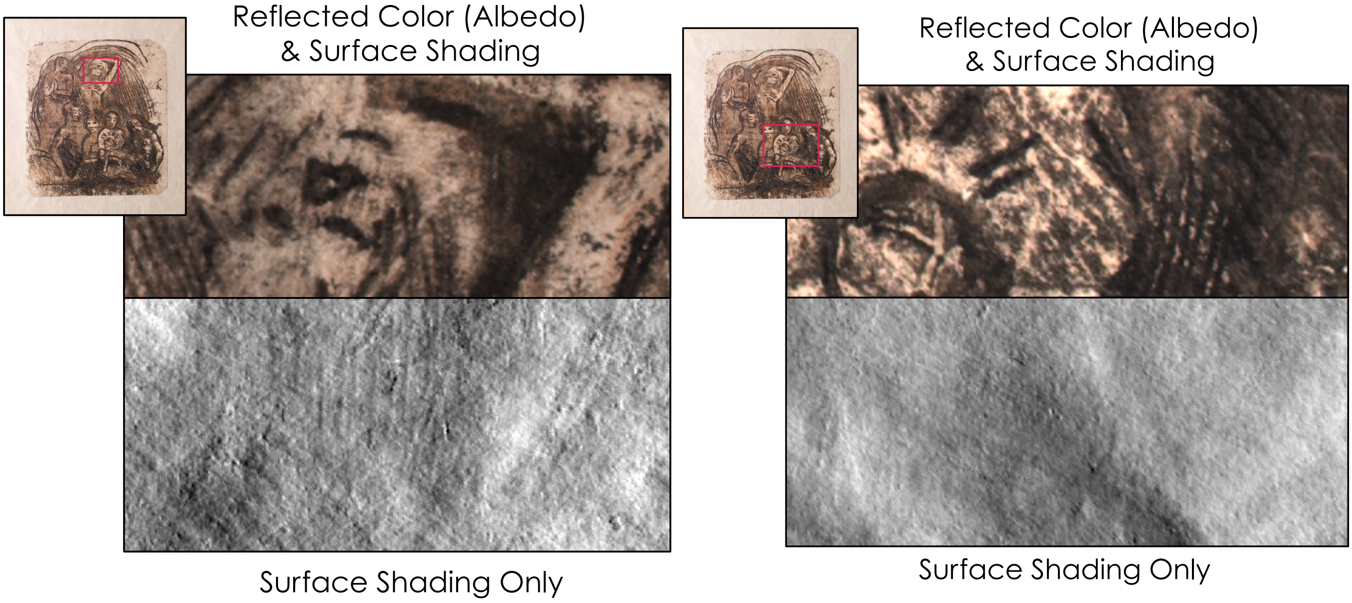
Fig. 8: Separating surface color from shading information for the 3D color calibration target. a) A captured photo of the calibration target. b) A relit photo synthesized from recovered normals visualizing surface shading independent of surface color.

"Blind Incising:" The second problem we sought to solve by measuring the surface shape of Gauguin's transfer drawing is the origin of the "blind incising." Fig. 9b shows clearly that there are no surface features at the locations of the blind incisions. This is solid evidence that the blind incisions do not originate from any indentations in the paper surface during ink transfer. But if they are not caused by the underlying shape of the paper surface, where do they come from?

IX. Interpretation of Results

We were surprised to discover no incising at all at the locations of the broken lines in Gauguin's transfer drawings. In puzzling over this curiosity, we started to map out where all the broken lines were on the paper. The result is shown in Fig. 11a. Upon reflecting on this image, a new idea started to emerge. Were we possibly looking at inverted impressions made from the inked support that Gauguin used in his studio more than a century ago? The plausibility of this theory seemed striking given the new-found evidence from the 3D surface measurements. Another fact that was made plain during our attempt to reproduce Field's method, was that an inked paper support was too absorbent and did not transfer the rich, furrowed lines that we observe in many of Gauguin's works. Even the most heavily sized paper allowed the ink that had been rolled out onto it to dry too quickly to produce a satisfactory mark, let alone the stray smudges and handprints, which significantly contribute to the tone and atmosphere of many of the artist's transfer drawings. Gauguin found these to be such happy accidents that he would subsequently apply pressure to the backs of his transfer drawings with a roller to ensure that they were amply reproduced. In order to transfer something as subtle as varied line width, and to assure that the lines previously inscribed in his printing matrix were resolved with clarity as a crisscrossing network of voids on the next print, we hypothesize that Gauguin was using not a sheet of paper as a carrier for the ink, but a sheet of glass. Based on this theory, we experimented with reproducing Gauguin's transfer techniques in attempt to further understand the process he used. After several experiments, we narrowed in on the following technique (Fig. 11b):

1) First, a standard monotype is made by placing a piece of paper on an inked surface (the glass matrix) and drawing on the back.
2) The monotype produced is removed from the glass matrix and set aside.



(a) Transferred Lines

(b) "Blind Incising"

Fig. 9: Surface shading information for regions in *Nativity* corresponding to transferred lines and "blind incising." a) The transferred lines show clear evidence of surface shapes that protrude from the page. b) No evidence of surface structure is present for regions corresponding to "blind incising," indicating the features do not originate from incising at all.

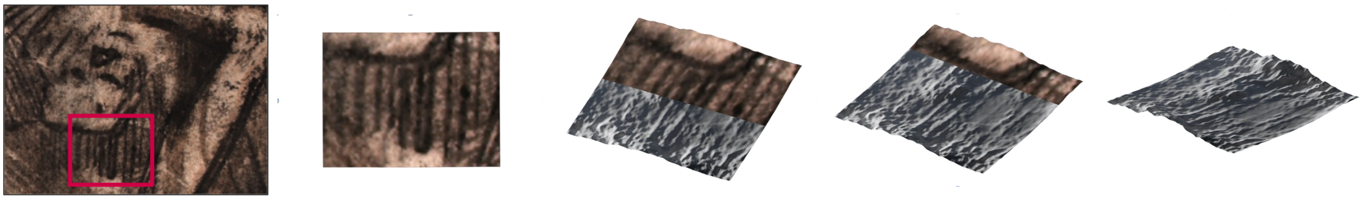


Fig. 10: Several frames from an animation visualizing the 3D surface shape at the location of the lines drawn in *Nativity*. The 3D reconstruction shows clear evidence of protrusions on the page where ink has been deposited. This is solid evidence of the ink being transferred from a matrix such as that in a monotype transfer process.

3) Now the glass matrix lacks ink in the locations where it was transferred to the first monotype.
4) We place a second piece of paper on the same inked surface; this piece of paper will eventually be our final transfer drawing.
5) We then draw on the back of this sheet of paper to transfer the initial ink layer, which in this example, is brown. In the process of making the drawing, fingerprints and marks from the pressure of the artist's hand on the paper, deliberately or inadvertently, are also transferred.
6) When we lift our sheet of paper from the matrix, we see that we have transferred inked lines to the surface, but the lines are broken in locations where ink was previously removed from the matrix while creating the first monotype.
7) We then place the same sheet of paper that now carries a brown ink impression onto a second glass matrix inked with darker pigment. This matrix is pristine.
8) We again draw on the back of the sheet to transfer the darker lines that form the second layer of transferred media.
9) When we remove the paper, the process is finished and we have created the final transfer drawing.

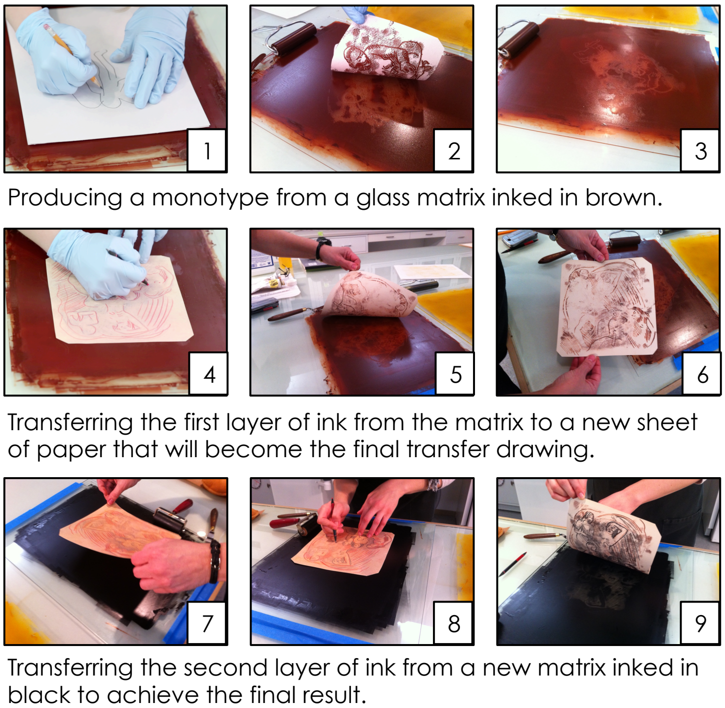
Fig. 13 shows a side-by-side comparison of the reconstruction and the original transfer drawing. The marks on the reconstruction appear visually consistent with the original.

X. Conclusions

In summary, we are trying to understand more about the experimental processes Gauguin used in his printed and transferred imagery. And while some details of his methods can be inferred from visual inspection alone, we believe we have uncovered greater insight into his processes by measuring the 3D surfaces of his prints and transfer drawings. We believe the techniques used here could be more generally useful in analyzing a larger body of works of art as well.

Moving forward, we plan to further evaluate our technique so that conservators can understand the precision of their measurements if they repeat our experiments on their own collections. As an example, by comparing with the calibration target, we can see that the depth of the lines is on the

(a) A map of the broken lines



(b) The nine-step transfer process

Fig. 11: Our new hypothesis of the transfer technique used to produce *Nativity* a) A map of the broken white lines in the transfer drawing shows where ink was removed from the glass matrix during the first step of the transfer process. b) A visual demonstration of the nine-step transfer process.

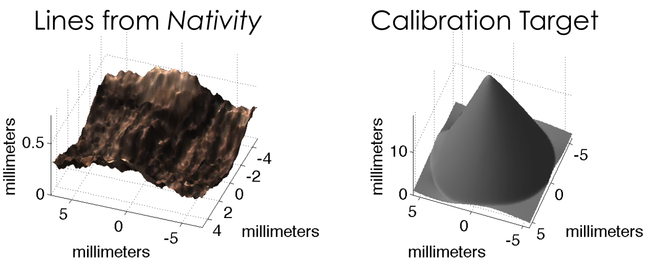


Fig. 12: Comparing the 3D reconstruction with the 3D calibration target. The height of the cone in the calibration target is approximately 10mm. The surface reconstruction of *Nativity's* protruding lines are approximately $100\times$ smaller, indicating they are on the order of $100\mu m$ in height.

order of 100s of microns (see Fig. 12). We also think the same reflectance data used to compute surface measurements can help us classify the materials used in each region of an artwork. For *Nativity*, this could help us separate the first and second layers of ink application. We hope this will help us better identify different forms in the broken lines in Gauguin's transfer drawings, and once we do that, we can begin to answer open questions as to whether they correspond to forms in other works. Lastly, the analysis we have presented here will be used to inform exhibitions and scholarly catalogs currently under development at the Art Institute of Chicago, including an online scholarly catalog of the museum's Gauguin holdings, and an upcoming exhibition planned for 2017 entitled *Gauguin: Artist as Alchemist*.

XI. Acknowledgement

This project was undertaken at the Northwestern University / Art Institute of Chicago Center for Scientific Studies in the Arts (NU-ACCESS). NU-ACCESS is funded through a generous grant from the Andrew W. Mellon Foundation. Supplemental support is provided by the Materials Research Center, the Office of the Vice President for Research, the McCormick School of Engineering and Applied Science and the Department of Materials Science and Engineering at Northwestern University.

References

[1] Beck, L.S., *Digital Documentation in The Conservation of Cultural Heritage: Finding the Practical in Best Practice*. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., 2013. XL-5-W2: p. 85-90.

[2] Gabov, A. and G. Bevan, *Recording the Weathering of Outdoor Stone Monuments Using Reflectance Transformation Imaging (RTI): The Case of the Guild of All Arts (Scarborough, Ontario)*. Journal of the Canadian Association for Conservation, 2011. 36: p. 3-14.

[3] Stratis, H.K., *Beneath the Surface: Redons Methods and Materials,* in Odilon Redon: Prince of Dreams. D. W. Druick, Editor. 1994, Art Institute of Chicago in association with H. N. Abrams.

[4] Stratis, H.K., *Innovation and tradition in Mary Cassatt's pastels: a study of her methods and materials,* in Mary Cassatt, Modern Woman. J.A. Barter, Editor. 1998, Art Institute of Chicago in association with H.N. Abrams.

[5] Zegers, P. K. , *In the Kitchen with Paul Gauguin: Devising Recipes for a Symbolist Graphic Aesthetic.* In The Broad Spectrum: Studies in the Materials, Techniques, and Conservation of Color on Paper, edited by H. K. Stratis and B. Salvesen, pp. 138-144. London: Archetype Books, 2002.

Fig. 13: Visual comparison between Gauguin's *Nativity* and the transfer drawing produced using our hypothesized transfer process. The marks on the reconstruction appear visually consistent with the original.

[6] Shugar, A. and J. Mass, *Handheld XRF for Art and Archaeology.* 2013, Leuven, Belgium: Leuven University Press.

[7] Delaney, J. K., et al., *Visible and Infrared Imaging Spectroscopy of Picasso's Harlequin Musician: Mapping and Identification of Artist Materials in Situ.* Applied Spectroscopy, 2010. 64(6): p. 584-594.

[8] Casadio, F., et al., *Identification of Organic Colorants in Fibers, Paints, and Glazes by Surface Enhanced Raman Spectroscopy.* Accounts of Chemical Research, 2010. 43(6): p. 782-791.

[9] Malzbender, T., D. Gelb, and H. Wolters. *Polynomial texture maps.* In Proceedings of the 28th annual conference on Computer graphics and interactive techniques. 2001. ACM.

[10] Earl, G., et al. *Reflectance transformation imaging systems for ancient documentary artefacts.* 2011. BCS.

[11] Earl, G., et al. *Polynomial texture mapping and related imaging technologies for the recording, analysis and presentation of archaeological materials.* in ISPRS Commission V Midterm Symposium, Newcastle, UK. 2010.

[12] Earl, G., K. Martinez, and T. Malzbender, Archaeological applications of polynomial texture mapping: analysis, conservation and representation. Journal of Archaeological Science, 2010. 37(8): p. 2040-2050.

[13] Fattal, R., M. Agrawala, and S. Rusinkiewicz, *Multiscale shape and detail enhancement from multi-light image collections.* In ACM Trans. Graph., 2007. 26(3): p. 51.

[14] Mudge, M., et al., *Image-based empirical information acquisition, scientific reliability, and long-term digital preservation for the natural sciences and cultural heritage.* In Eurographics Tutorials, 2008.

[15] Padfield, J., D. Saunders, and T. Malzbender, Polynomial texture mapping: a new tool for examining the surface of paintings. ICOM Committee for Conservation, 2005. 1: p. 504- 510.

[16] Malesevic, B., et al., *Application of polynomial texture mapping in process of digitalization of cultural heritage.* arXiv preprint arXiv:1312.6935, 2013.

[17] Abbaspour, M., et al., *OBJECT:PHOTO, Modern Photographs.* The Thomas Walther Collection, 1909-1949, New York: The Museum of Modern Art, 2014.

[18] Mudge, M., et al. New Reflection Transformation Imaging Methods for Rock Art and Multiple-Viewpoint Display. in VAST. 2006. Citeseer.

[19] Mudge, M., et al. *Reflection transformation imaging and virtual representations of coins from the hospice of the grand st. bernard.* in Proceedings of the 6th International conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage. 2005. Eurographics Association.

[20] Nicodemus, F.E., J.C. Richmond, and J.J. Hsia, *Geometrical considerations and nomenclature for reflectance.* Vol. 160. 1977: US Department of Commerce, National Bureau of Standards Washington, D. C.

[21] Woodham, R. J. 1980. *Photometric method for determining surface orientation from multiple images.* Optical Engineerings 19, I, 139-144.

[22] Frankot, R. T., and Chellappa, R., *A Method for Enforcing Integrability in Shape from Shading.* IEEE PAMI Vol 10, No 4 July 1988. pp 439-451

[23] Field, R. S. *Paul Gauguin: Monotypes*. 1973. Philadelphia Museum of Art.